TP 14495E

Development of an Intelligent Sign Management System

Prepared for:
Transport Canada

By:

DELCAN

November 2005

106-02830/

TP 14495E

Development of an Intelligent Sign Management System

Prepared for:
Transport Canada

By:

DELCAN

November 2005

TP 14495E

Development of an Intelligent Sign Management System

by

R. Chylinski and N. Chiang

Transportation Systems Division

DELCAN Corporation

November 2005

This report reflects the views of the authors and not necessarily those of Transport Canada.

This project is part of Canada's Intelligent Transportation Systems (ITS) R&D plan, *Innovation Through Partnership*, funded by the ITS Office of Transport Canada under the Strategic Highway Infrastructure Program (SHIP).

The Transportation Development Centre of Transport Canada served as technical authority for this project.

Project Team

T. Schnarr, Delcan Corporation, Project Director
R. Chylinski, Delcan Corporation, Project Manager
G. Marcu, Delcan Corporation
N. Chiang, Delcan Corporation

Un sommaire français se trouve avant la table des matières.

Transport Canada Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No. TP 14495E	2. Project No.	3. Recipient's Catalogue No.
4. Title and Subtitle Development of an Intelligent Sign Management System		5. Publication Date November 2005
		6. Performing Organization Document No.
7. Author(s) R. Chylinski and N. Chiang		8. Transport Canada File No. 2450-GP009
9. Performing Organization Name and Address Delcan Corporation 625 Cochrane Drive, Suite 500 Markham, Ontario Canada L3R 9R9		10. PWGSC File No. 052ss.T8663-030015
		11. PWGSC or Transport Canada Contract No. T8663-030015/001/SS
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 800 René Lévesque Blvd. West Suite 600 Montreal, Quebec H3B 1X9		13. Type of Publication and Period Covered Final
		14. Project Officer Brian Marshall

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

This project is part of Canada's Intelligent Transportation Systems (ITS) R&D Plan, *Innovation Through Partnership*, funded by the ITS Office of Transport Canada under the Strategic Highway Infrastructure Program (SHIP). The Transportation Development Centre of Transport Canada served as technical authority for this project.

16. Abstract

This document summarizes the work undertaken for the Development of an Intelligent Sign Management System (ISMS). The purpose of the project was to research and define an intelligent sign management methodology that allows the generation of location-specific messages based on multiple traffic condition criteria and knowledge of current operation strategies. The goal is to provide the foundations for significant advancement in current freeway traffic management practices.

This project began with extensive research of existing Changeable Message Sign (CMS) message generation systems worldwide and potential intelligent designs in the area of sign management and response plan operations. As a result of the research, a rule-based approach was adopted due to its flexibility in response to system changes. Some requirements, such as automatic event response and an easy-to-use rule editing tool, were suggested to enhance the system functions. A prototype ISMS was designed to include four processes: event assessment, sign selection, message composition and multiple-message handling. All associated rules for each process were further defined. The ISMS prototype was developed with three components: an XML rule-based engine (including all rules), a digital road/sign navigation map and a user interface. A system evaluation using COMPASS output from the Ministry of Transportation of Ontario was conducted to validate the performance of the prototype system.

The results of the evaluation showed that the ISMS prototype produced valid responses and reduced traffic response database maintenance significantly (e.g., reduced to a few minutes). This concept was proven to be an effective and efficient tool for intelligent sign management systems.

17. Key Words Rule base, traffic response plan, advanced traffic management system, ATMS, XML, intelligent sign management system, ISMS	18. Distribution Statement Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication) Unclassified	20. Security Classification (of this page) Unclassified	21. Declassification (date) —	22. No. of Pages xiv, 19, apps	23. Price Shipping/ Handling

Canada

Transports Canada Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. Nº de la publication de Transports Canada TP 14495E	2. Nº de l'étude	3. Nº de catalogue du destinataire

4. Titre et sous-titre

Development of an Intelligent Sign Management System

5. Date de la publication

Novembre 2005

6. Nº de document de l'organisme exécutant

7. Auteur(s)

R. Chylinski et N. Chiang

8. Nº de dossier - Transports Canada

2450-GP009

9. Nom et adresse de l'organisme exécutant

Delcan Corporation
625 Cochrane Drive, Suite 500
Markham, Ontario
Canada L3R 9R9

10. Nº de dossier - TPSGC

052ss.T8663-030015

11. Nº de contrat - TPSGC ou Transports Canada

T8663-030015/001/SS

12. Nom et adresse de l'organisme parrain

Centre de développement des transports (CDT)
800, boul. René-Lévesque Ouest
Bureau 600
Montréal (Québec)
H3B 1X9

13. Genre de publication et période visée

Final

14. Agent de projet

Brian Marshall

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

Ce projet fait partie du Plan de R&D du Canada sur les systèmes de transports intelligents (STI), *Innover par l'établissement de partenariats*, financé par le Bureau des STI ainsi que par Transports Canada dans le cadre du programme stratégique d'infrastructures routières (PSIR). Le Centre de développement des transports de Transports Canada a agi comme responsable technique pour ce projet.

16. Résumé

Le présent rapport résume les travaux réalisés en marge du projet de développement d'un système intelligent de gestion de panneaux à message variable (SIGPMV). Ce projet consistait à définir une méthode intelligente de gestion de panneaux à message variable, qui permet d'élaborer des messages adaptés à chaque panneau, selon des critères liés à l'état de la circulation et une base de connaissances sur les stratégies opérationnelles en vigueur. Le but poursuivi est de jeter les bases d'une évolution majeure des pratiques actuelles de gestion de la circulation autoroutière.

Le projet a commencé par une étude fouillée des systèmes d'élaboration de messages pour panneaux à message variable (PMV) actuellement utilisés dans le monde, et des concepts «intelligents» applicables à la gestion de panneaux de signalisation et aux plans d'intervention d'urgence en matière de circulation. Cette étude a mené à l'adoption d'une approche à base de règles, en raison de sa souplesse en cas de modifications apportées au système. On a suggéré de poser certaines exigences pour améliorer les fonctions du système, comme la réponse automatique à un événement et un outil convivial de modification des règles. Un prototype de SIGPMV a été conçu, doté des quatre processus suivants : évaluation des événements, sélection des panneaux, élaboration des messages et traitement de messages multiples. Toutes les règles associées à chaque processus ont ensuite été définies. Le prototype de SIGPMV comprend trois composants : un moteur basé sur des règles XML (y compris toutes les règles), une carte numérique des routes/panneaux de signalisation et une interface utilisateur. Une évaluation du système à l'aide de COMPAS, du ministère des Transports de l'Ontario, a eu lieu, afin de valider le rendement du prototype.

L'évaluation a montré que le prototype de SIGPMV générait des interventions valides et que la maintenance de la base de données des interventions était grandement accélérée (ne nécessitant plus que quelques minutes). Le concept s'est donc avéré convenir tout à fait aux systèmes intelligents de gestion de panneaux à message variable.

17. Mots clés

Base de règles, plan d'intervention d'urgence en matière de circulation, système avancé de gestion de la circulation, SAGC, XML, système intelligent de gestion de panneaux à message variable, SIGPMV

18. Diffusion

Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	—	xiv, 19, ann.	Port et manutention

CDT/TDC 79-005
Rev. 96

Canada

ACKNOWLEDGEMENTS

The cooperation and the valuable participation of the Development of ISMS Steering Committee members are gratefully acknowledged:

Brain Marshall, Transport Canada, Transportation Development Centre
Madeleine Betts, Transport Canada, ITS Office
Henry Wong, Ministry of Transportation of Ontario, ITS Office
Emmanuel Morala, Ministry of Transportation of Ontario, ATMS
David Tsui, Ministry of Transportation of Ontario, ATMS

EXECUTIVE SUMMARY

The Ontario Ministry of Transportation's (MTO) COMPASS, a high-tech highway traffic management system deployed in 1991, uses state-of-the-art technologies and is regarded as one of the most advanced traffic management systems in North America. COMPASS provides timely and accurate highway incident and delay information to motorists via Changeable Message Signs (CMS). A system evaluation study indicated that COMPASS helps to reduce traffic congestion and increase safety. Over the years, the Highway 401 COMPASS System has been upgraded and expanded. During that process, four objectives were identified for future system improvements to reduce traffic response plan maintenance efforts, improve suitability of pre-determined traffic response plans to each incident, improve system capability to handle multiple events, and reduce human error in selecting a response plan.

This research project was initiated to develop an innovative system concept in response to the above objectives. In cooperation with the Ontario Ministry of Transportation, the project was conducted in four stages: literature review, system design, prototype development, and system evaluation.

Researchers conducted an extensive literature search worldwide and selected seven systems for review. From the designs of these systems, three main approaches (i.e., table-lookup, program/rule-based and expert system/rule-based) were identified and evaluated with criteria such as automation, flexibility, comprehension, development effort, etc. A rule-based design approach was recommended and some useful system features from the system review were also suggested as requirements for system design.

A system concept was proposed based on the rule-based approach and requirements identified in the previous stage. The system concept included event assessment, equipment selection and message determination. This design can incorporate all current traffic response strategies (e.g., lane usage, speed control, traveller information) and different means of information dissemination (e.g., CMS, website, fax messages). It also includes functions identified in the previous stage such as event combination, multiple message handing, equipment availability, and operator intervention. A user-friendly and English-like rule development environment was then defined based on the system concept. An example rule set using the MTO's CMS signing strategy was developed to explain how to build rules in this rule development environment.

In order to prove the concept, a prototype of the Intelligent Sign Management System (ISMS) was developed by applying Extensible Markup Language (XML) technologies. This prototype consisted of an XML Generator / Analyzer, XML Grammar and XML Editor. Grammar and Editor were used to define rule hierarchy and key phrases used in rule sets and to enter the rule sets. The rule hierarchy can be either sign-driven or event-driven depending on the needs of local traffic management practices. The Generator / Analyzer was an XML rule-based engine that uses the predefined XML Grammar to determine traffic responses such as sign actions and site management instructions. This prototype was integrated with a digital map and a navigation database used to search event and sign locations. The example CMS signing strategy rules defined in the event-driven hierarchy were inputted into the XML Rule Database.

A system evaluation was conducted by reviewing outputs from the prototype system and MTO COMPASS under 13 operation and maintenance scenarios such as typical incident, road works, or weather events, locations of two events that are close, adding a new rule, etc. The system evaluation environment used a section of Highway 401 between Highway 400 and Victoria Park Avenue with 16 CMS signs. These 16 signs are all one size (i.e., 3 lines X 30 characters). The results of the evaluation demonstrated that the ISMS can not only produce credible responses, but also perform advanced functions like event combination, multiple message handling, etc. The evaluation also found that the effort for maintaining the rule database and adding new signs required only a few minutes, compared to the existing MTO process, which involves several days of effort.

In conclusion, the concept of the ISMS was proven to provide a more efficient, flexible, cost-effective, and powerful Advanced Traffic Management System (ATMS) environment. This prototype has the potential to be adopted in a full implementation of an ATMS as well as the potential to be applied in other regions within Canada or other countries. A few extensions and further work are recommended as follows:

- This concept would need to be extended to manage the update and termination phases in order to manage the full event life cycle.

- Manual modification of the suggested traffic responses would need to be included to allow users to change the traffic responses based on their practical judgment.

- The prototype would need to be extended to include additional rules to be able to generate different message content to fit various sign types.

SOMMAIRE

Le système COMPAS du ministère des Transports de l'Ontario (MTO), un système de gestion de la circulation routière d'avant-garde mis en place en 1991, s'appuie sur des technologies de pointe et est considéré comme l'un des systèmes de gestion de la circulation les plus évolués en Amérique du Nord. COMPAS transmet en temps voulu aux usagers de la route une information précise sur les incidents de la circulation et les embouteillages, au moyen de panneaux à message variable (PMV). Une évaluation du système a indiqué que COMPAS contribue à réduire la congestion routière et à accroître la sécurité sur les routes. Au fil des ans, le système COMPAS de la route 401 a été amélioré et étendu. Dorénavant, l'amélioration du système poursuivra quatre objectifs, soit alléger le travail de mise à jour des plans d'intervention d'urgence en matière de circulation, faire en sorte que les plans d'intervention préétablis soient mieux adaptés aux incidents, améliorer la capacité du système de traiter des événements multiples et réduire l'erreur humaine dans le choix d'un plan d'intervention.

Ce projet de recherche avait pour but de concevoir un système novateur qui permettrait d'atteindre les objectifs susmentionnés. Mené en collaboration avec le ministère des Transports de l'Ontario, le projet comportait quatre étapes : recherche documentaire, conception du système, développement d'un prototype et évaluation du système.

Les chercheurs ont étendu leur recherche documentaire à l'ensemble de la planète et ont soumis sept systèmes à un examen approfondi. De l'étude de ces systèmes sont ressorties trois principales approches (consultation de table, base de programmes/règles et système expert à base de règles), qui ont été évaluées en regard de critères comme l'automatisation, la souplesse, la compréhension, le travail de développement exigé, etc. Une approche à base de règles a été recommandée et certaines fonctions utiles, dérivées de la revue des systèmes, ont également été suggérées en tant qu'exigences pour la conception du système.

Un concept de système a été proposé, qui respectait l'approche à base de règles et les exigences définies à l'étape précédente. Ce concept comprenait l'évaluation des événements, la sélection d'équipement et la détermination du message. Le système peut intégrer toutes les stratégies d'intervention existantes (p. ex., ouverture/fermeture de voies, limitation de la vitesse, information aux voyageurs) et différents moyens de communication (p. ex., PMV, site Web, télécopieur). Il comprend également des fonctions déterminées à l'étape antérieure, comme la combinaison d'événements, le traitement de messages multiples, la disponibilité d'équipement et l'intervention de l'opérateur. Pour l'élaboration des règles, un environnement convivial, utilisant l'anglais, a été défini, à partir du concept de système. Un ensemble de règles type a été élaboré à partir de la stratégie de conception des messages des PMV du MTO, afin d'illustrer comment se construisent les règles dans un tel environnement.

Pour valider le concept, on a développé un prototype de système intelligent de gestion de panneaux à message variable (SIGPMV) à l'aide des technologies de langage de balisage extensible (XML). Ce prototype comportait un générateur/analyseur XML, une grammaire XML et un éditeur XML. La grammaire et l'éditeur ont servi à définir la hiérarchie des règles et les expressions clés utilisées dans les ensembles de règles, et à entrer les ensembles de règles. Les règles peuvent être hiérarchisées en fonction des

panneaux de signalisation ou des événements, selon les pratiques locales de gestion de la circulation. Le générateur/analyseur était un moteur basé sur des règles XML, qui utilise la grammaire XML prédéfinie pour déterminer les interventions d'urgence en matière de circulation (comme l'affichage de message sur les PMV) et des instructions concernant la gestion du lieu de l'incident. Ce prototype a été intégré à une carte numérique et une base de données de navigation, qui servent à localiser les événements et les panneaux. Les règles régissant la stratégie type d'élaboration des messages des PMV ont été hiérarchisées en fonction des événements et entrées dans la base de données des règles XML.

Pour évaluer le système, on a comparé les résultats du prototype à ceux du COMPAS du MTO, dans 13 scénarios d'exploitation et de maintenance, par exemple un incident type, des travaux routiers ou des événements météorologiques, la proximité spatiale de deux événements, l'ajout d'une nouvelle règle, etc. Le système a été évalué pour le tronçon de la route 401 situé entre la route 400 et Victoria Park Avenue, qui comprend 16 PMV. Les 16 panneaux sont identiques (3 lignes et 30 caractères par ligne). L'évaluation a montré que le SIGPMV peut non seulement mener à des interventions crédibles, mais aussi réaliser des fonctions évoluées comme la combinaison d'événements, le traitement de messages multiples, etc. L'évaluation a également révélé que le temps nécessaire à la maintenance de la base de données de règles et à l'ajout de nouveaux panneaux de signalisation n'était que de quelques minutes, comparativement au temps actuellement requis par les mêmes tâches dans le système du MTO, soit plusieurs jours.

En conclusion, le concept du SIGPMV s'est révélé offrir un environnement plus efficace, plus souple, plus économique et plus puissant pour un système avancé de gestion de la circulation (SAGC). Ce prototype peut être adopté pour une mise en œuvre intégrale d'un SAGC ou encore pour une application dans d'autres régions du Canada ou à l'étranger. Quelques travaux sont encore recommandés :

- Étendre le concept à la gestion des phases de mise à jour et de clôture, de façon qu'il gère tout le cycle de vie de l'événement.
- Inclure la possibilité de modifier manuellement les interventions suggérées afin que les utilisateurs puissent modifier les interventions selon leur bon jugement.
- Inclure des règles supplémentaires qui permettraient d'élaborer différents contenus de message pouvant être acceptés par divers types de panneaux.

TABLE OF CONTENTS

1 INTRODUCTION 1

1.1 Project Background 1
1.2 Project Overview 2
1.3 Scope of Document 2

2 LITERATURE REVIEW 3

2.1 Review Process 3
2.2 System Review 3
2.3 Evaluation Results 4
2.4 Conclusions 5

3 SYSTEM DESIGN 6

3.1 System Function and Requirements 6
3.2 Traffic Response Principles 6
3.3 System Design Overview 8
3.4 Traffic Response Rules 9
3.4.1 Example of Rule Sets 9
3.4.2 Description of Rules 9

4 SOFTWARE DEVELOPMENT 13

5 SYSTEM EVALUATION 15

5.1 Evaluation Environment and Scenarios 15
5.2 Evaluation Criteria 16
5.3 Evaluation Results 16

6 CONCLUSIONS AND RECOMMENDATIONS 18

6.1 Conclusions 18
6.2 Recommendations 19

APPENDICES

A Technical Report on Existing CMS Message Generation Techniques
B Technical Report on New CMS Message Generation Techniques
C Evaluation Report on New CMS Message Generation Techniques

LIST OF TABLES

Table 2-1: Summary of Selected System Designs....4
Table 2-2: Summary of Analysis of System Design Approaches....5
Table 3-1: Control Strategy Identification....7

LIST OF FIGURES

Figure 3-1: System Structure....8
Figure 4-1: System Components....13

GLOSSARY

AID	Automatic Incident Detection
ATIS	Advanced Traveller Information System
ATMS	Advanced Traffic Management System
Caltrans	California Department of Transportation
CCTV	Closed Circuit Television
CMS	Changeable Message Sign
CSLS	Changeable Speed Limit Sign
DMS	Dynamic Message Sign (Alternative to CMS)
ECA	Event-condition-action
FELG	Facility, Event, Location and Guidance (message format)
FTMS	Freeway Traffic Management System
IMES	Incident Management Expert System
ISMS	Intelligent Sign Management System
ITS	Intelligent Transportation Systems
LCS	Lane Control Signal
MTO	Ministry of Transportation of Ontario
NADICS	National Driver Information and Control System (Scotland)
TCSS	Traffic Control and Surveillance System
TFB	Taiwan Freeway Bureau
TOD/DOW	Time-of-Day/Day-of-Week
VDS	Vehicle Detector Station
VMS	Variable Message Sign (alternative to CMS)
XML	Extensible Markup Language

1 INTRODUCTION

1.1 Project Background

The project to develop an Intelligent Sign Management System (ISMS) was proposed by a team of Delcan Corporation and Ontario Ministry of Transportation (MTO) ATMS experts in response to a call for proposals from Public Works and Government Services Canada for the development of innovative ITS projects under the Intelligent Transportation Systems Research and Development Plan, Research and Development Contract funding mechanism.

Traffic management technologies have been applied intensively in Advanced Traffic Management Systems (ATMS) to provide accurate and timely information concerning incidents, congestion or road conditions to motorists. Most current traffic management practices to generate appropriate traffic responses are based on pre-determined plans and/or manual control. These traffic response plans are usually location-specific and condition-specific (i.e., traffic conditions and incident conditions). As a result, numerous plans have to be built into the response database. During system operation and maintenance, some restrictions and operational costs might be imposed:

- The response plans may not always be well suited to the exact location and conditions of an incident, as they are predefined and quite specific (in terms of location and condition characteristics).
- Due to significant reliance on an operator's input for the selection and execution of a response plan, there is potential for human error and mistakes that could adversely affect the sign and message selection.
- Maintenance of the response plan database is troublesome and very labour-intensive when the system is expanded geographically (to cover additional areas) or due to changes to the system configuration (equipment location, etc.).
- Current signing strategy is primarily based on a prescribed event type priority, and only one event type message can be displayed at a time.

Thus, a new methodology is proposed to generate location-specific messages based on multiple traffic condition criteria and knowledge of current operations strategies. It shall also overcome the abovementioned restrictions.

1.2 Project Overview

The purpose of the project was to develop a concept of an ISMS that allows the generation of location-specific messages based on multiple traffic condition criteria and knowledge of current operation strategies. The goals to be achieved were:

- To manage "multiple conditions/incidents" simultaneously, including information such as travel time, road conditions, special situations, incidents and safety;
- To automatically resolve sign message conflicts without operator involvement;
- To manage a network of freeways;
- To use multi-phased messages;
- To vary strategies by "time-of-day / day-of-week" (TOD/DOW) or level of congestion; and
- To add new signs without requiring response plan changes.

Benefits of the new methodology include providing better traffic information to the motorist, thus enhancing safety and reducing driver frustration, and reducing congestion. In addition, the operation and maintenance costs would be reduced due to the deployment of new signs and operational strategies.

1.3 Scope of Document

This document summarizes the detailed findings and conclusions of the project and is organized based on its major tasks:

- Literature Review
- System Design
- Software Development
- System Evaluation
- Conclusion and Recommendations

2 LITERATURE REVIEW

A literature review was conducted to research academic methodologies and existing ATMS systems worldwide. Seven systems were selected for detailed review. In this review, details of each system were described to include system background, system description and user experience. These systems were then categorized into three system approaches. An evaluation of the three system approaches was performed to identify the system functions and requirements for developing the concept of ISMS. The "Technical Report on Existing CMS Message Generation Techniques" is attached as Appendix A.

2.1 Review Process

Academic research was conducted using two approaches:

- Reviewing existing CMS message generation systems worldwide; and
- Investigating current potential intelligent designs in the area of sign management and response plan operations.

Seven Advanced Traffic Management Systems (ATMS's), which were either in operation or in the design concept stage, were identified and are briefly described in Section 2.2:

1. Ministry of Transportation of Ontario (MTO) COMPASS;
2. California Department of Transportation (Caltrans) ATMS;
3. Illinois State Toll Highway Authority Traffic and Incident Management System;
4. Hong Kong Department of Transportation Traffic Control and Surveillance System;
5. Taiwan Freeway Bureau ATMS's;
6. Texas Transportation Institute Incident Management Expert System; and
7. UK (Scotland) National Driver Information System.

2.2 System Review

A system review included the background, description, and user experience for each of the seven ATMS's. The background described basic information such as the year of development, system coverage, traffic control equipment types, and event types. The description addressed the system design, including system approach and development tools as well as some valuable system functions. The user experience summarized the advantages and shortcomings. The systems were then summarized according to six goals, as summarized in Table 2-1.

Table 2-1 : Summary of Selected System Designs

Goals / Designs	Manage multiple conditions/ incidents simultaneously	Resolve sign message conflicts automatically	Manage a network of freeways	Use multi-phased messages	Vary strategies by TOD/DOW or level of congestion	Require no plan changes with new signs
MTO	+	-	+	-	-	-
California	+	+	+	-	+	+
Illinois	+	+	+	-	-	+
Hong Kong	+	-	-	-	-	-
Taiwan	+	+	+	+	+	+
Texas	-	-	-	-	+	-
UK	+	-	+	-	-	-

Legend: + : Feature is included

- : Feature is not included

2.3 Evaluation Results

The evaluation process first categorized the seven systems into three types: table-lookup, rule-based program and expert system. A qualitative analysis using five groups of criteria (automation, flexibility, comprehension, expandability, and development effort) was completed. Automation considered the systems' abilities to automatically provide traffic impact assessment and traffic responses. Flexibility considered features such as equipment availability, equipment changes, response practice changes and system adaptability to technology transfer and future upgrades. Comprehension focused on the levels of complexity to developers and operational staff to learn the application tools and to operate the system. Expandability investigated the efforts needed to expand the systems' coverage and add more traffic response practices. Development effort reviewed design, development and testing effort. The summary table for this evaluation is illustrated in Table 2-2.

Table 2-2: Summary of Analysis of System Design Approaches

Design Approaches	Table-Lookup	Rule-Based Program	Expert System
Automation			
Automatic traffic impact assessment	-	+	+
Automatic response plan suggestion	-	+	+
Flexibility			
Equipment and personnel availability	-	+	+
Equipment relocation	-	+	+
Local practice changes	-	+	+/-
Technology transfer	-	-	+/-
Comprehension			
Learning curve	+	+/-	-
Staff experience	+/-	+	+
Expandability			
New control areas and/or equipment	-	+	+
New rules	-	+	+
Development Effort			
System development	+	-	-
Testing of plans	+	-	-

Legend:
+ : Requirement is highly satisfied
- : Requirement is not satisfied
+/- : Requirement is somewhat satisfied

2.4 Conclusions

A rule-based design approach (either rule-based program or expert system) was recommended as the proposed method for the ISMS. In addition, as a result of the review of the seven systems, several valuable features are suggested to enhance the system functions:

- Automatic event response process;
- Verification of equipment and personnel availability;
- Easy editing of the rule base, without the user requiring detailed knowledge of the expert system or program languages; and
- Capability of manually modifying a system-recommended response plan.

3 SYSTEM DESIGN

The system design addressed system functional requirements, traffic response principles, system structure and processes, and the details of the associated rules for each process. The "Technical Report on New CMS Message Generation Techniques" is attached as Appendix B.

3.1 System Function and Requirements

The system functional requirements were identified from the system goals as well as from the conclusion of the "Technical Report on Existing CMS Message Generation Techniques". These are summarized as follows:

- Adopt the rule-based approach;
- Handle multiple messages automatically;
- Automate the event response process;
- Verify equipment and personnel availability;
- Provide a easy rule editing tool without requiring detailed knowledge of the expert system or program languages; and
- Allow manual modification of a system-recommended response plan.

3.2 Traffic Response Principles

A traffic response process is a combination of actions in response to an event and current roadway conditions. This process covers three aspects: event assessment, traffic response strategy identification and traffic response generation.

Event assessment is usually performed by the traffic operator prior to traffic response plan initiation. Events are assessed according to category, severity and diversion strategy. All events are categorized into six types: lane-blocked incident, congestion, road work, road condition, special events, and safety. The factors to be considered in determining levels of severity are event type, event location (mainline or ramp), blockage pattern, current traffic condition and event clearance time. Total roadway blockage resulting from an incident or planned work requires traffic diversion.

The traffic response strategy identification determines which of the five traffic response strategies – traveller information, speed control, lane usage control, ramp metering, or queue end warning – are to be used. Table 3-1 summarizes the findings.

Table 3-1: Control Strategy Identification

Event type	Traveller Information	Speed Control	Lane Usage Control	Ramp Metering System	Queue End Warning
Lane-blocked incident	Y	Y	Y	Y	Y
Congestion	Y	Y	-	Y	Y
Roadwork	Y	Y	Y	Y	Y
Road Condition (rain, wind, or fog)	Y	Y	–	–	–

Legend Y: recommended for the event type
–: not recommended

Once the traffic response strategies are identified, traffic response generation then implements two processes: control point selection (i.e., signs or ramps) and message determination (e.g. CMS displayed messages or speed limits).

The concept of ISMS was designed to follow traffic response principles and to account for all traffic response strategies. However, the logic applied in selecting control points and determining messages for each traffic response strategy is quite different. The effort required to address the details for every traffic response strategy is tremendous. Since this project is a proof of concept, only one traffic response strategy – traveller information – was selected to be developed in the rule database of the prototype system for evaluation. This strategy, which utilizes CMS's, to disseminate travel information or warnings to motorists, is the most commonly used and effective traffic response strategy in ATMS. The rule development is further explained in Section 3.4 and uses CMS's, as an example. Other traffic response strategies could be incorporated into the prototype in the future without changing the concept by simple expansion of the rules.

The following system operations were considered to be implemented in the prototype system:

• Event Combination:	Combine multiple events and reduce the number of messages to be displayed.
• Highway Network:	Integrate the signs on connecting freeways to provide advance warnings to the drivers on connecting freeways.
• Message Composition:	Use variables and phrases according to the message pattern to determine the message.
• Multiple-phase Messages:	Consider multiple-phase messages or combined messages.
• Operator Intervention:	Allow operator to verify and to modify the output.

3.3 System Design Overview

The system structure was designed to account for all types of traffic control strategies. The system comprises two types of controllable objects: event and equipment. The properties of the objects are controlled by three processes: event assessment, sign selection and message determination (message composition and multiple message handling). These processes contain rules based on traffic response principles that generate appropriate traffic responses. The system structure is illustrated in Figure 3-1.

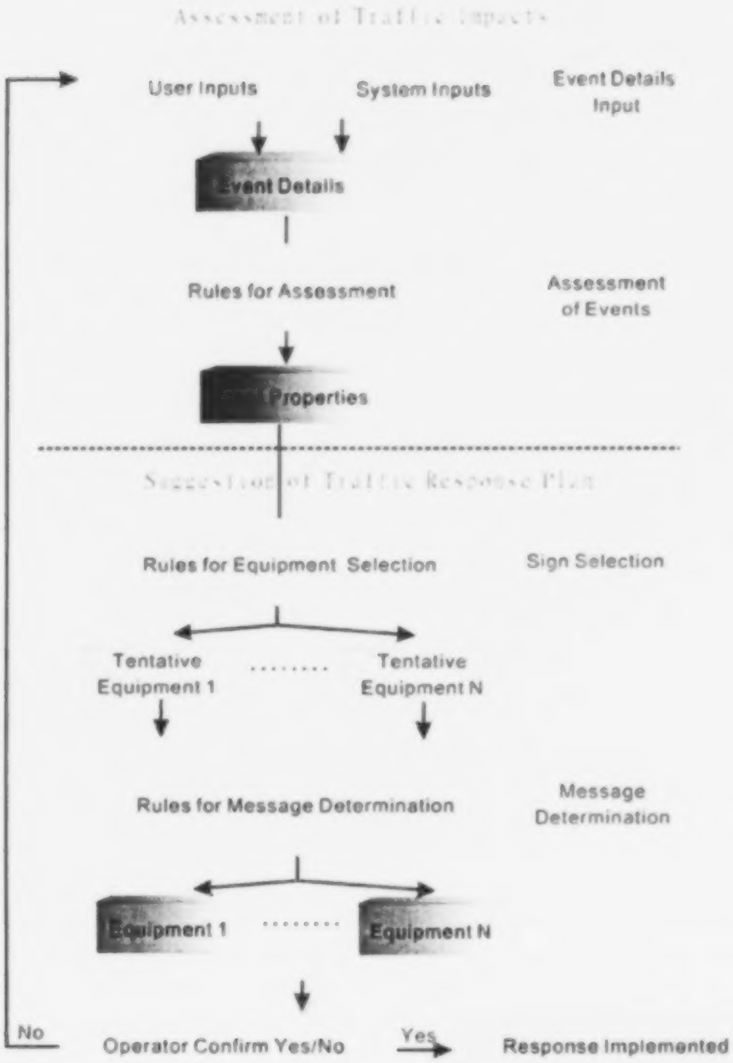
Assessment of Traffic Impacts
User Inputs
System Inputs
Event Details Input
Event Details
Rules for Assessment
Assessment of Events
Properties
Suggestion of Traffic Response Plan
Rules for Equipment Selection
Sign Selection
Tentative Equipment 1
Tentative Equipment N
Rules for Message Determination
Message Determination
Equipment 1
Equipment N
No
Operator Confirm Yes/No
Yes
Response Implemented

Figure 3-1: System Structure

3.4 Traffic Response Rules

This section describes how the traffic response rules were defined through an example of rule sets. These rule sets, developed to generate traffic responses for CMS's, cover several processes such as event assessment, equipment selection and message determination.

It should be noted that as standard practice, many operating systems use various CMS types of different sizes that result in various message formats. However, different message formats would be a simple extension of the concept. One sign size – 30 characters per line and 3 lines per sign – was selected for the development of the prototype.

3.4.1 Example of Rule Sets

Rules consist of two parts: "if" conditions and "then" actions. The rule sets for event assessment, sign selection, message determination and multiple sign handling are defined as follows:

- If the event details are inputted, then determine the event conditions such as event type, severity and diversion.
- If event conditions are met, then select the number of upstream CMS signs.
- If event conditions and sign conditions, such as the relative location of the sign to the event, are met, then compose a message for the sign.
- If a sign is assigned two messages, then use multiple message handling.

3.4.2 Description of Rules

The rules defined for event assessment, sign selection, message composition and multiple message handling are described, respectively, as follows:

1. **Event Assessment**

   Event assessment determined three event properties based on the event details: event type, severity and diversion. Four event types were considered for the prototype system: lane-blocked incident, roadway maintenance, congestion and road condition. When an event is initiated, it is assigned to an event type based on a predefined table. Three severity levels are used: low, medium and high. The severity level is determined based on event type, event location (mainline or ramp), blockage pattern, current traffic condition (i.e., light, medium or heavy), and other factors. Diversion is decided based on blockage pattern only. Figure

3-2 illustrates how the event assessment rules are constructed. For severity, the factors shown in the different coloured boxes represent whether different event types are used to determine the level of severity for that event.

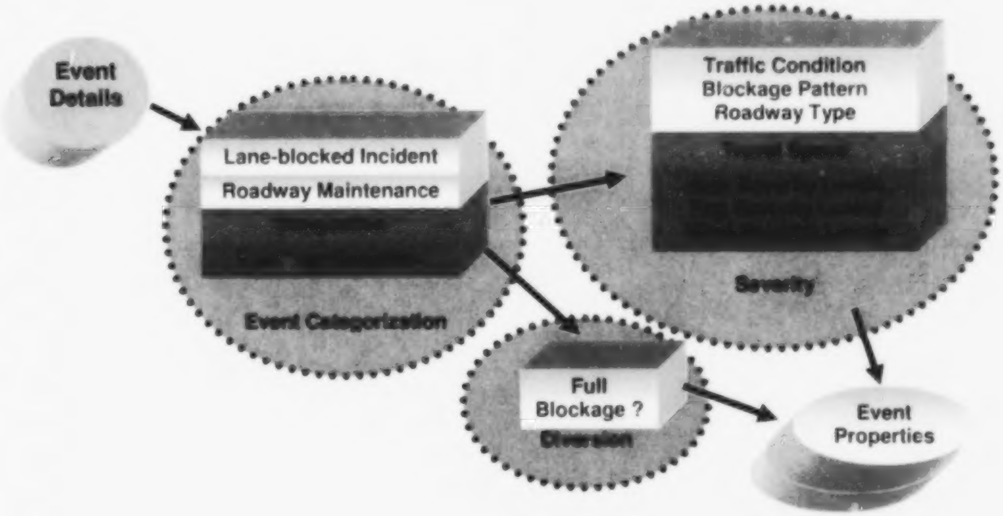
Event Details
Lane-blocked Incident
Roadway Maintenance
Event Categorization
Traffic Condition
Blockage Pattern
Roadway Type
Severity
Full Blockage ?
Diversion
Event Properties

Figure 3-2: Event Assessment Rule Diagram

2. Sign Selection

Sign selection determined how many upstream signs should be activated for displayed messages. The rules defined for the prototype are as follows:

- If the event category is congestion, then choose one upstream sign.
- If the event category is other categories, then:
    - If the severity is low, then choose one upstream sign.
    - If the severity is medium, then choose two upstream signs.
    - If the severity is high, then choose three upstream signs.

- If the furthest upstream sign is not working, then choose the next sign further upstream.

- If there is a connecting freeway within the sign extents, then choose the first sign from both directions for message display.

The rules are illustrated in Figure 3-3.

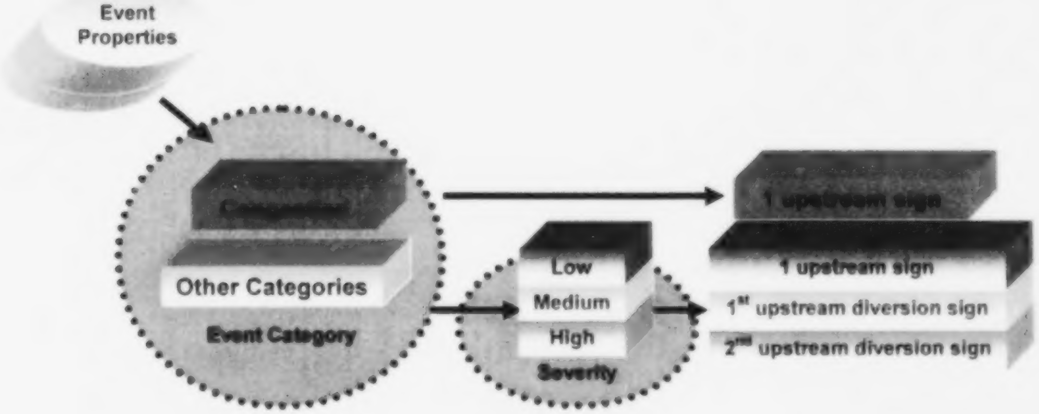
Event Properties
Other Categories
Event Category
Low
Medium
High
Severity
1 upstream sign
1 upstream sign
1st upstream diversion sign
2nd upstream diversion sign

Figure 3-3: Sign Selection Rule Diagram

3. Message Composition

The message composition for each sign followed the facility, event, location and guidance (FELG) pattern. The typical message format has variables per line as follows:

Line 1: {Facility} {Event Type}
Line 2: {Event Location}
Line 3: {Guidance}

Each variable in braces has various phrases for message composition. The phrases are predefined and used when conditions are met. Example phrases are listed as follows:

- Facility:

  Express, Collector, Hwy 401

- Event Type:

  Congestion, {Blockage Pattern} Lane Blocked, Severe Rain, Fog, Strong Wind

- Event Location:

  {At/before/beyond} {ramp} --- if event location is a point
  From {ramp} to {ramp} --- if event location is a range

3-2 illustrates how the event assessment rules are constructed. For severity, the factors shown in the different coloured boxes represent whether different event types are used to determine the level of severity for that event.

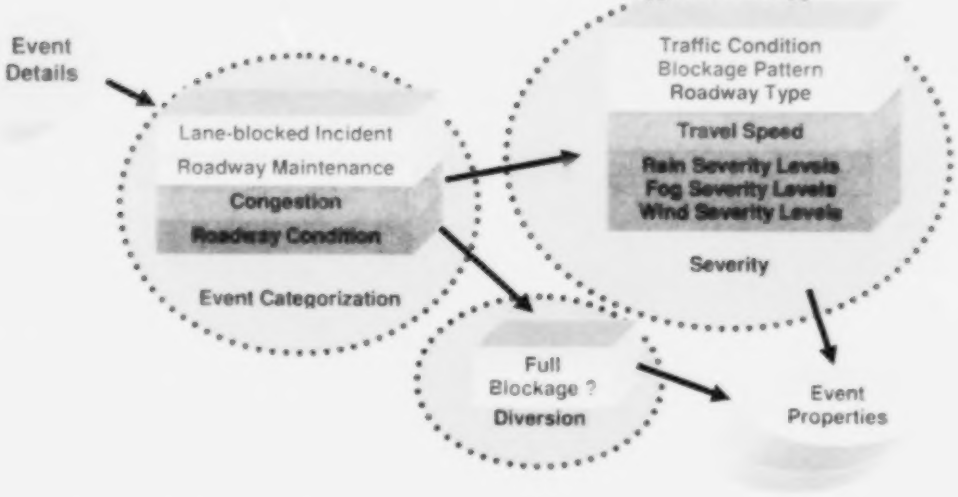
Event Details
Lane-blocked Incident
Roadway Maintenance
Congestion
Roadway Condition
Event Categorization
Traffic Condition
Blockage Pattern
Roadway Type
Travel Speed
Rain Severity Levels
Fog Severity Levels
Wind Severity Levels
Severity
Full Blockage ?
Diversion
Event Properties

Figure 3-2: Event Assessment Rule Diagram

2. Sign Selection

Sign selection determined how many upstream signs should be activated for displayed messages. The rules defined for the prototype are as follows:

- If the event category is congestion, then choose one upstream sign.
- If the event category is other categories, then:
    - If the severity is low, then choose one upstream sign.
    - If the severity is medium, then choose two upstream signs.
    - If the severity is high, then choose three upstream signs.
- If the furthest upstream sign is not working, then choose the next sign further upstream.
- If there is a connecting freeway within the sign extents, then choose the first sign from both directions for message display.

The rules are illustrated in Figure 3-3.

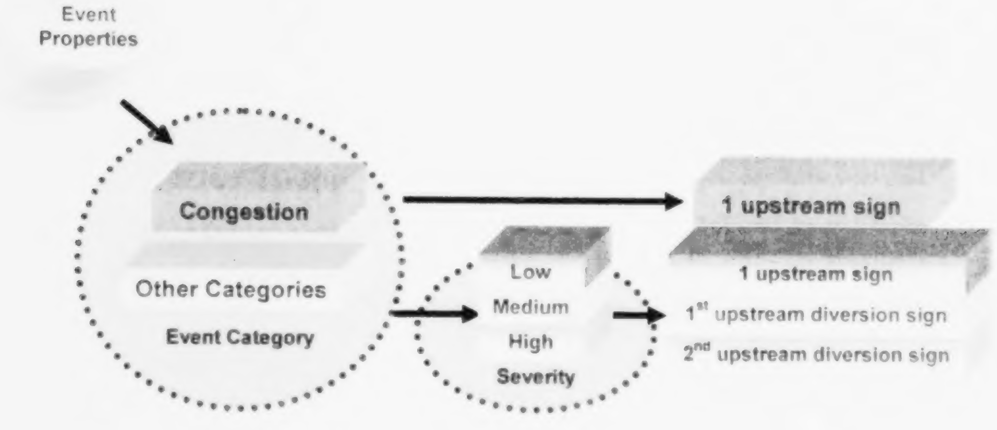
Event
Properties
Congestion
Other Categories
Event Category
Low
Medium
High
Severity
1 upstream sign
1 upstream sign
1st upstream diversion sign
2nd upstream diversion sign

Figure 3-3: Sign Selection Rule Diagram

3. Message Composition

The message composition for each sign followed the facility, event, location and guidance (FELG) pattern. The typical message format has variables per line as follows:

Line 1: {Facility} {Event Type}
Line 2: {Event Location}
Line 3: {Guidance}

Each variable in braces has various phrases for message composition. The phrases are predefined and used when conditions are met. Example phrases are listed as follows:

- Facility:

  Express, Collector, Hwy 401

- Event Type:

  Congestion, {Blockage Pattern} Lane Blocked, Severe Rain, Fog, Strong Wind

- Event Location:

  {At/before/beyond} {ramp} --- if event location is a point
  From {ramp} to {ramp} --- if event location is a range

- Guidance:

  This is optional and is currently applied to conditions such as traffic diversion, severe weather and emergency stop. Following are some example rules:

  - If traffic diversion is needed and the sign is the first diversion point, then use “Traffic Must Exit at {ramp}”.
  - If traffic diversion is needed and the sign is the second or third diversion point, then use “Traffic Use {ramp}”.
  - If event is severe weather, then use “Drive with Care”.
  - If the sign is very near to the event, and
    - If no traffic diversion is needed, then use “Prepare to Stop”.
    - If traffic diversion is needed, then use “Emergency Stop”.

4. Multiple Message Handling

When a sign is assigned two messages, the rules to handle multiple messages for the prototype system are as follows:

- If upstream travel speed is less than X km/h (i.e., 20 km/h), then display two messages in rotation.
- If upstream travel speed is more than X km/h (i.e., 20 km/h), then combine two messages.

4 SOFTWARE DEVELOPMENT

Extensible Markup Language (XML) is one of the most widely adopted technologies for information exchange and representation. This technology, with the capability of event-condition-action (ECA) rules, was selected for our rule-based application. Therefore, ISMS software development was implemented in the XML environment following the guidelines specified in the System Design. The overview of the prototype ISMS design is illustrated in Figure 4-1.

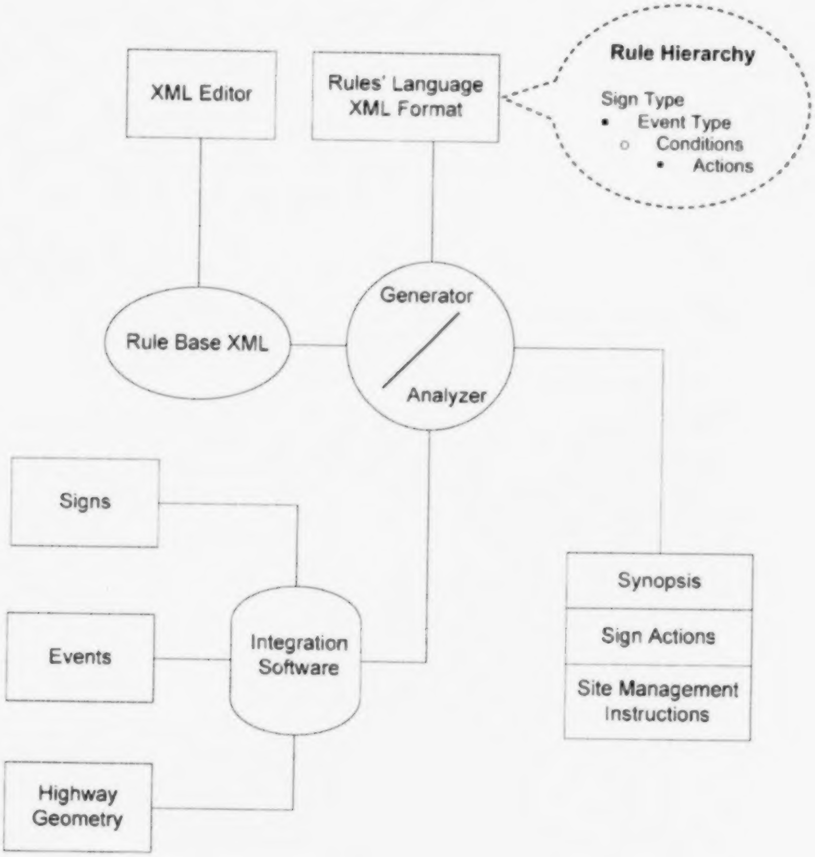
XML Editor
Rules' Language XML Format
Rule Hierarchy
Sign Type
Event Type
Conditions
Actions
Rule Base XML
Generator
Analyzer
Signs
Events
Integration Software
Highway Geometry
Synopsis
Sign Actions
Site Management Instructions

Figure 4-1: System Components

XML Format is where users define their rule hierarchy. The rules for each sign type are aggregated in one group. The rule hierarchy for each sign type consists of three levels: event type, conditions and actions. Users can define key phrases for event type, conditions and actions to be used in building rules. The **Generator / Analyzer** is the XML rule-based engine. It uses the predefined **XML Format** to interpret the **Rule Base XML**, where all the rules are located, to determine traffic responses such as **Synopsis**,

Sign Actions, and **Site Management Instructions**. This engine was also integrated with the Navigation Database in Delcan's Traffic Control and Surveillance System (TCSS) software for obtaining information such as sign and event locations as well as highway geometry.

The rule hierarchy in the XML Grammar can be either a sign-driven or event-driven hierarchy, depending on the needs of local traffic management practices. The sign-driven hierarchy describes how a sign shall react in response to various events which occur. The event-driven hierarchy describes how adjacent signs shall react in response to a specific event. The example rules developed in the system design task were defined in the event-driven hierarchy and inputted into the prototype.

The developed software application with 12 test scenarios was demonstrated to the Steering Committee in March 2005.

5 SYSTEM EVALUATION

ISMS was designed to provide a more powerful, flexible and efficient environment for ATMS. The concept of ISMS was validated though an evaluation under several typical scenarios. This evaluation compared ISMS outputs against MTO COMPASS outputs, which represent current traffic management practices, to verify whether ISMS could produce credible or better responses. During the evaluation, the flexibility and cost effectiveness that ISMS could bring to the ATMS environment were also reviewed. The results of the evaluation prove that the concept did provide better performance. The "Evaluation Report on New CMS Message Generation Techniques" is attached as Appendix C.

5.1 Evaluation Environment and Scenarios

The environment for the system evaluation used a section of Highway 401 in Toronto, Ontario, between Victoria Park Avenue and Highway 400. This highway network is a good example of how the designed system handles complex roadway geometry situations. This section has express and collector lanes running parallel with two connecting highways (i.e., Highway 404 and Allen Road) and eight crossroads. A total of 16 CMS's are installed in this section.

Thirteen typical scenarios were simulated for evaluation. The content of each scenario included purpose, existing traffic condition prior to the event, event details, ISMS output, COMPASS output, evaluation comments and actions. In normal practice, the condition of an event will change as time evolves and thus the traffic management process in response to the event includes three stages: event initiation, event update and event termination. The traffic responses generated for each stage are different due to the differences of event conditions. However, these traffic responses are based on the same traffic management principles. To validate the concept of ISMS, the initiation part of the event was simulated for each scenario. The event update and event termination parts were not included because the traffic response generation process simply repeats. The scenarios were as follows:

1. Shoulder Blockage Incident
2. Partial Blockage Incident
3. Collector Total Blockage Incident
4. Collector & Express Total Blockage Incident
5. Express Congestion
6. Collector Total Blockage Roadwork
7. Severe Rain
8. Event Combination 1 (Stalled Vehicle and Traffic Collision)
9. Event Combination 2 (Previous Condition and Traffic Congestion)
10. Display Multiple Messages
11. Multiple Stages of an Event
12. Add a New Sign
13. Change Rules

5.2 Evaluation Criteria

The evaluation was conducted by reviewing the outputs generated by ISMS and COMPASS from the 13 scenarios. The output from each system included the activated signs and their displayed messages. Because COMPASS and the ISMS prototype were developed based on different approaches (table-lookup and rule-based approaches), the outputs from both systems would be similar to some extent but not identical. The following criteria were used for evaluation:

1. Number of activated CMS's

   The number of activated CMS's shall be the same and the locations of the activated signs shall be the same.

2. Similarity of message content

   The message content shall be similar in the message pattern. The message pattern used in many regions covers three items:
   a. Problem (i.e., event)
   b. Location
   c. Advisory (optional)

   The details in each item are subject to local practices. If the messages from both systems address the problem and the event location, then they are deemed as similar.

In addition to comparing the outputs from both systems, the rule development environment was also evaluated. The criterion used for evaluation was the time required to change or add rules.

5.3 Evaluation Results

Output from the ISMS prototype and COMPASS were collected. There was no COMPASS output for Scenarios 7 to 10, and 12 and 13 due to the fact that there were no similar functions in its original design. Although no output was obtained for comparison, the ISMS produced credible responses for these scenarios, which proved that the prototype has advanced features such as event combination and multiple-message handling to enhance the system functions.

The evaluation was conducted twice for scenarios with output from two systems. In the first evaluation, there were some discrepancies between the two systems because of differences in the systems' traffic principles and because traffic congestion caused by the event was not included as the second event. After the appropriate actions were implemented, the second evaluation was conducted, and it showed that the results from the ISMS prototype were aligned with those of MTO COMPASS. The results of the evaluation are summarized as follows:

1. During the evaluation process, traffic responses collected from COMPASS included traffic congestion. However, traffic responses from ISMS were generated based on the assumption that the upstream traffic was not severely affected at the beginning of the event. This assumption yielded the differences in traffic responses between ISMS and COMPASS in terms of the number of signs and message content. After adding a traffic congestion event into the evaluation scenarios, the results from the ISMS matched those of COMPASS. Scenario 2 is a good example of this. In addition, the sign messages generated by ISMS combined information concerning the incident and the congestion, while COMPASS displayed messages on a single-event basis.

2. The message sign content from COMPASS was similar but not identical to that of ISMS because the ISMS message content design adopted a general format and was not specific to the needs and sign sizes of COMPASS. The description of the general format, including the problem, location and advisory, is commonly used in most ATMS's. The message content is subject to the practices of the local jurisdiction's traffic engineers.

3. For Scenario 3 – Collector Total Blockage Incident, the number of activated signs and messages generated by the ISMS was different from COMPASS. This difference was because the rule set for this scenario was different from the practice used in COMPASS. The upstream boundary of the sign selection was extended to Victoria Park Avenue. After the rule was adjusted, the results from the ISMS matched COMPASS. It is important to note that the rule change was completed within 5 minutes, and the test repeated. This demonstrates the ease of maintenance of the ISMS.

4. For Scenario 5 – Express Congestion, the number of activated signs and message content of ISMS were different from COMPASS due to the differences in traffic response strategies between ISMS and COMPASS. The strategy used in ISMS was to tackle the queue condition and the range, while COMPASS monitors the congestion level of the congestion zone. COMPASS activated one sign in the upstream and ISMS activated three signs to advise the drivers caught in, and upstream of, the queue in both Express and Collector lanes to be cautious. The sign messages generated by the ISMS displayed locations of queues; messages from COMPASS displayed the congestion level of the congestion zone. The traffic response strategy for congestion in the ISMS provides more information on queues and is currently adopted in many regions; therefore, this strategy remains the same.

5. For those scenarios in which traffic principles needed to be modified or a new sign was added, the effort spent in making these changes is reduced to a few minutes (i.e., 5 minutes). The ISMS prototype produced appropriate outputs for all roadway sections. It showed that the concept could improve the way the rules were developed or maintained.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The Intelligent Sign Management System (ISMS) provides a more powerful, flexible and efficient environment for an Advanced Traffic Management System (ATMS). The concept of the ISMS was developed by identifying useful system requirements through a literature review on selected existing systems and research papers. The system design, which takes into consideration identified system requirements, all advanced highway traffic management strategies (e.g., traveller information, ramp metering, lane usage control), operation and maintenance issues, and development efforts, includes the system structure, four system functions and the description of the rule format. To prove the system concept, a prototype was developed with several sample rules that apply the traveller information strategy (i.e., changeable message signs) for generating responses to major traffic events. This prototype was validated through an evaluation of the traffic responses generated from both MTO COMPASS and the ISMS prototype. The evaluation results show that the concept surpasses conventional methods. As a result of this project, the ISMS was proven to be:

1. Qualified, because a general set of rules was able to generate traffic responses that matched specific COMPASS response scenarios. Applied to other highway sections, this set of rules generated similar results.

2. Efficient, because the time required to define and modify rules took as little as a few minutes.

3. Flexible and easy for traffic engineers to update, because rules were specified in plain English (i.e., English phrases used to describe events, conditions and actions) and did not require knowledge of computer programming or other software programs.

4. Cost effective, because it was developed using the XML language, which is free, easy to use, and in common use in many web information exchange applications.

The following full technical reports for each of the major tasks are included as appendices to this document:

- Technical Report on Existing CMS Message Generation Techniques
- Technical Report on New CMS Message Generation Techniques
- Evaluation Report on New CMS Message Generation Techniques

6.2 Recommendations

ISMS is a prototype system that proves that a rule-based concept using non location-specific rules can produce valid responses for freeway traffic management systems. Although the sample rules were based on only changeable message signs, the rule logic can be extended to incorporate other field traffic control devices, such as lane control signs, variable speed limit signs, ramp metering, etc, as well as disseminate information to users or other agencies through website messages, fax messages, etc. The concept is also flexible in that either a sign-driven or event-driven hierarchy can be applied to build up the rules. Thus, this prototype has the potential to be adopted in a full implementation of an Advanced Traffic Management System. The following extensions and further work are recommended:

1. Some functions and requirements that are necessary to facilitate the daily ATMS operational activities were not included in the prototype:

    - Automatic event assessment; and
    - Manual modification of the suggested traffic responses.

    Automatic event assessment determines the event properties and impact on the traffic conditions. Manual modification of the suggested traffic responses allows users to change the suggested traffic responses based on their practical judgment.

2. The ISMS currently manages only the initiation of the event. In order to manage the full event life cycle, it would need to be extended to manage the update and termination phases.

3. The ISMS currently manages one sign type. Most operational systems use several sign types; therefore, the ISMS would need additional rules to be able to determine the appropriate message content depending on the sign type.

The ISMS prototype has been further improved to include the functions recommended above. The enhanced system is currently used in TCSS projects recently initiated by the Hong Kong Government.

APPENDIX A

Technical Report on Existing CMS Message Generation Techniques

TABLE OF CONTENTS

Page

1.0 Introduction 1
  1.1 Purpose 1
  1.2 Document Organization 1
2.0 Review Process 3
3.0 Description of Selected System Designs 4
  3.1 MTO Design 4
    3.1.1 System Background 4
    3.1.2 System Description 5
    3.1.3 User Experience 6
  3.2 Caltrans Design 7
    3.2.1 System Background 7
    3.2.2 System Description 8
    3.2.3 User Experience 10
  3.3 Illinois Design 10
    3.3.1 System Background 10
    3.3.2 System Description 11
    3.2.3 User Experience 14
  3.4 Hong Kong Design 14
    3.4.1 System Background 14
    3.4.2 System Description 15
    3.4.3 User Experience 17
  3.5 Taiwan Design 17
    3.5.1 System Background 17
    3.5.2 System Description 17
    3.5.3 User Experience 19
  3.6 Texas Design 19
    3.6.1 System Background 19
    3.6.2 System Description 20
    3.6.3 User Experience 21
  3.7 UK Design 22
    3.7.1 System Background 22
    3.7.2 System Description 23
    3.7.3 User Experience 25
  3.8 Summary of Selected System Designs 26
4.0 Analysis of Design Approaches 27
  4.1 Methodology 27
  4.2 Categorization 27
  4.3 Evaluation Items 28
  4.4 Analysis of Three Typical Design Approaches 29
    4.4.1 Automation 29
    4.4.2 Flexibility 30

4.4.3 Comprehension 30
4.4.4 Expandability 31
4.4.5 Development Effort 31
5.0 Conclusions 33
Bibliography 35

LIST OF TABLES

Table A3.1 Definition of Message Template Variables
Table A3.2 Event Categories and Types
Table A3.3 Distance Limits
Table A3.4 Summary of Selected System Designs
Table A4.1 Summary on Analysis of System Design Approaches

ACRONYMS

The acronyms used in this document are defined as follows:

AID	Automatic Incident Detection
ATIS	Advanced Traveller Information System
ATMS	Advanced Traffic Management System
Caltrans	California Department of Transportation
CCTV	Closed Circuit Television
CITRAC	Centrally Integrated Traffic Control
CLIPS	C-Language Integration Production System
CMS	Changeable Message Sign
CSLS	Changeable Speed Limit Sign
GCM	Gary-Chicago-Milwaukee
HOV	High Occupancy Vehicle
IMES	Incident Management Expert System
LCS	Lane Control Signal
MTO	Ministry of Transportation of Ontario
NADICS	National Driver Information and Control System (Scotland)
PLEG	Problem Location Effect Guidance
TCSS	Traffic Control and Surveillance System
TFB	Taiwan Freeway Bureau
TIMS	Traffic and Incident Management System
TOD/DOW	Time-of-Day/Day-of-Week
VDS	Vehicle Detector Station

1.0 Introduction

1.1 Purpose

The objective of this project was to research and develop a concept for an Intelligent Changeable Message Sign (CMS) Message Manager. In essence, research was conducted in defining an intelligent CMS management methodology to allow the generation of location-specific messages based on multiple traffic condition criteria and knowledge of current operation strategies. The project's goal is to provide the foundation in advancing freeway traffic management practices.

Four working stages were proposed by Delcan to achieve the objective of this project: literature review and actual needs assessment; intelligent sign management system design; demonstration system implementation; and system evaluation.

This report summarizes the essential findings from the literature review and the needs assessment conducted in Stage 1. The main goal of these tasks was to present a clear picture of the current state of sign management strategies and methodologies in Advanced Traffic Management Systems. The findings of this report will be used as a foundation for developing an intelligent sign management system.

1.2 Document Organization

This report is divided into five sections:

1. Introduction
   The purpose and structure of this report are addressed.

2. Review Process
   The detailed research methodology is described.

3. Description of Selected System Designs
   This section reviews several typical system designs. The review includes system or project background, CMS message generation system description, and user experience. The section concludes with a summary of how the seven reviewed system designs addressed each of the identified objectives for the proposed intelligent sign management system.

4. Analysis of Design Approaches
   This section first categorizes the reviewed systems into several design approaches, lists the evaluation criteria, and then addresses how these systems satisfied the evaluation criteria.

5. Conclusions
   Conclusions are drawn based on the results of the analysis described in the previous section.

2.0 Review Process

Academic research was conducted through two approaches:

- Reviewing the existing CMS message generation systems worldwide; and
- Investigating current potential intelligent designs in the area of sign management and response plan operations.

From these two approaches, the following seven Advanced Traffic Management Systems (ATMS's), which were either in operation or in the design concept stage, were identified, and are briefly described in Section 3 of this report:

- Ministry of Transportation of Ontario (MTO) COMPASS;
- California Department of Transportation (Caltrans) ATMS;
- Illinois State Toll Highway Authority Traffic and Incident Management System;
- Hong Kong Department of Transportation Traffic Control and Surveillance Systems;
- Taiwan Freeway Bureau ATMS's;
- Texas Transportation Institute Incident Management Expert System; and
- UK (Scotland) National Driver Information System.

Together, the seven identified ATMS's provide detailed examples of the following three typical design approaches to response plan and CMS message generation:

- Table-lookup of a pre-defined set of response plans;
- Hard coded program based a logical rule set; and
- Expert system program employing a logical rule set.

3.0 Description of Selected System Designs

3.1 MTO Design

3.1.1 System Background

The Ministry of Transportation of Ontario (MTO), operating within the Province of Ontario, Canada, is responsible for managing the province's COMPASS system – the ATMS that integrates incident management and congestion management along selected portions of the province's 400 series highways.

The goal of COMPASS is to reduce delays and accident risks through rapid detection, rapid response and removal, and efficient management of the incident events and traffic congestion. The CMS signing informs motorists of incidents and traffic conditions ahead in order for them to make decisions on route choice (e.g., between the parallel 'express' and 'collector' roadways) to improve travel time and to avoid accidents.

COMPASS manages traffic along Highway 401, and on connecting freeways leading into Highway 401, within the Greater Toronto Area. The initial COMPASS system was implemented in 1991 and covered a distance of 16 km along Highway 401 through the centre of Toronto. Over the subsequent years, the system has been expanded to currently cover a distance of over 59 km. The system currently controls and monitors numerous equipment including more than 630 vehicle detector stations, approximately 100 CCTV surveillance cameras, and 33 CMS's.

The ATMS continuously collects real-time traffic data using vehicle detectors, calculates traffic congestion levels, and executes Automatic Incident Detection (AID) algorithms to detect traffic incidents. System operators also continuously observe CCTV camera monitors to manually detect incidents and congestion. The System operators respond to identified incidents and adverse traffic conditions by dispatching pre-defined response plans that include pre-determined CMS messages.

The ATMS also has the capability to automatically respond to measured levels of traffic congestion by continually updating the CMS messages (without operator intervention) with congestion management messages. Such messages are intended to identify the end of traffic queues and balance the traffic flow between the parallel 'express' and 'collector' roadways.

The COMPASS CMS's have the capability of showing both graphic symbols and/or text messages.

3.1.2 System Description

a. Design Approach

A COMPASS response plan consists of a recommended list of CMS's and the associated messages that each of the CMS's should display. The response plan and messages are pre-defined by MTO's traffic engineers, and are kept in a CMS message library for use in the ATMS. The messages are designed to respond to specific types of events/incidents and severity levels for specific locations. As the system coverage of the highway is extended, the traffic engineers have to add new response plans to the response plan database, with text messages composed to specifically sign each potential event/incident.

Under normal operating conditions, no CMS message composition is required by the operators during operation. This approach was implemented in order to:

- Ensure consistency of response and message format for events/incidents of similar location, traffic condition, type and severity, which in turn facilitates public education regarding the intent and purpose of the message; and
- Minimize operator response time in dispatching a response plan.

To respond to any unusual or special circumstances, operators also have the ability, with the approval of their supervisors, to create and dispatch ad-hoc messages.

b. Detail Description

The CMS messages are pre-defined to respond to a variety of situations; not only incidents, but also special situations, congestion levels, and scheduled events. The 'scheduled event' messages also include traffic safety messages.

Messages dispatched to the CMS's are displayed based on the message type and the priority assigned to that message type, and are stacked in a CMS message priority queue within each CMS sign. There are four basic message types and the priority assigned to these message types, in descending order, is as follows:

- Operator-confirmed Messages:
  - Incident, special event or manual control message;
- Automatic Messages:
  - Congestion management message;
  - Scheduled event message; and
  - Default Message.

Incident, special event and manual control messages, which are the highest priority, are all messages types that are first confirmed by an operator prior to being displayed on a CMS. Only one operator confirmed message (i.e., incident, special event or manual control message) is kept in the CMS priority queue at any one time; the latest operator command will override any previous incident, special event or manual control message dispatched to the sign. For example, the latest message dispatched in response to an incident will overwrite a previously dispatched incident message. Note that the decision on whether to overwrite a previous operator-confirmed message is at the discretion of the operator at the time that he confirms the scope of the latest response plan being implemented.

Once an operator-confirmed message is removed from the sign, and the operator accepts the automatic message being proposed by the ATMS, then the CMS works in an automatic mode. In this mode, the ATMS automatically determines and dispatches the messages to be displayed on the CMS. Any congestion management message to be displayed will have priority over any scheduled event message or the default message. The latest congestion management message will automatically overwrite any previous congestion management message. If there is no congestion management message to be displayed, then any scheduled event message will be displayed. If there is no congestion management or schedule event message to be displayed, then the default message will be displayed.

c. Other Special Features

To reduce the number of individual CMS messages required to be defined for any given location, and hence, to reduce the number of messages in the CMS library, message templates are used. With message templates, system-generated information is used to 'fill-in' information in the CMS message about the incident type (e.g., collision, road works), lane blockage condition, and location relative to the freeway exit, while still providing a consistent response and message format.

To reduce the number of response plans used in the system, similar incidents identified within a specific freeway section will generate the same response plan.

3.1.3 User Experience

With 13 years of experience in operating the COMPASS system, the MTO has observed the following comments regarding the CMS management operations:

- In general, pre-defined response plans work well for incident management. In particular, this design approach ensures consistency of response and message format for events/incidents of similar location, traffic condition, type and severity, which in turn facilitates public education regarding the intent and purpose of the message.

- For a freeway as complex as the Highway 401 corridor (with parallel express and collector lanes in most but not all freeway sections), the standard message format, however, may not always be the most suitable. For example, the incident response plan format currently only addresses lane blockage; in some situations, it may be useful to provide other additional information to motorists.

- Another advantage of pre-defined response plans is that they are generally easy and quick for the operators to implement.

- Operators typically only encounter difficulty when a new response plan conflicts with a currently implemented response plan, and the operator needs to make decisions on which current CMS messages must be overwritten by the new response plan.

- Further to the above point, the current signing strategy is primarily based on a prescribed event type priority, and only one incident / special event type message can be displayed at a time. The MTO envisage that this is a principal area in which operational improvements would be both desirable and beneficial.

- For an existing ATMS operation, maintenance of the response plan database is minor; the response plan database seldom requires updates due to changes to the system and/or roadway configuration.

- For an extension of the system to another new geographical area, the development of new response plans can be a labour intensive and time consuming task, depending on the scope of the system extension.

3.2 Caltrans Design

3.2.1 System Background

The Caltrans Advanced Transportation Management System (ATMS) has been built to assist traffic operation staff with managing congestion on over 520 miles (837 km) of freeway network within District 7 of the State of California. The system was first developed in 1997.

The ATMS controls and monitors numerous equipment including 1,200 vehicle detector stations, 850 ramp metering stations, 350 CCTV surveillance cameras, and over 100 CMS's.

The Caltrans District 7 ATMS includes an event management subsystem that will help the operator in determining the actions to be taken in response to an incidents, emergency closures, and scheduled events. The event management subsystem includes both system-generated and pre-defined response plans and CMS messages.

3.2.2 System Description

a. Design Approach

Two types of response plans are provided: system-generated plans and pre-defined plans. The system-generated response plans are based on a standard set of rules that have been developed through a detailed analysis by experts in freeway management. This type of plan consists of the following three components:

- An operator action response plan;
- A freeway CMS response plan; and
- An Advanced Traveller Information System (ATIS) advisory response plan.

To generate response plans, the ATMS uses an expert system (i.e., G2 knowledge-based real-time expert system), which makes recommendations based on the set of pre-defined rules. For example, the expert system may have a rule that recommends the issue of a travel advisory for a lane-blocking incident lasting more than 30 minutes.

New rules are needed whenever the system is expanded. The modification would only involve reconfiguration of CMS locations.

The pre-defined type of response plans allows an operator to manually select individual CMS's, and their corresponding pre-defined messages, from the response plan library.

b. Detail Description

The system-generated response plans are determined by the system. The system requires the operator to manually input event details as follows:

- Location (roadway type, freeway, direction and nearest cross street);
- Time (time that users confirm the event);
- Event type (i.e., 29 types including vehicle fire, overturned truck, bomb threat, stall vehicle, earthquake, traffic collision, etc.); and

- Event details (i.e., blockage pattern, number of vehicle, number of injuries/fatalities, other attributes).

Based on these details, the system generates the following other event properties based on a set of pre-determined rules:

- Time of day (i.e., peak, high off-peak, low off-peak, etc.);
- Estimated clearance time; and
- Traffic impacts (i.e., high, medium or low based on combinations of time of day, estimated clearance time, type of roadway, number of lanes blocked and incident type).

Then, based on the event properties and other event details, the system searches for matching response 'criteria' rules and determines the recommended operator actions, CMS response plan and ATIS response plan.

The recommended operator actions focuses on communications between agencies and serve as a guide for assisting the operators to more efficiently accomplish transportation management functions.

The intent of the CMS response plan is to respond to non-recurring congestion by providing early warning to drivers of potential delays ahead, so that they have an opportunity to alter their route choice if desired. The system employs the following steps to generate the response plan:

1. Determination of the signing extent (i.e., the number of upstream critical interchanges), based on the following criteria:
   - Type of roadway (e.g., mainline, connecting freeway, HOV lanes, etc);
   - Traffic impact (high, medium and low); and
   - Exceptions due to the locations of logical diversion points.

2. Sign availability

3. Selection of CMS message templates for each CMS, using the following criteria:
   - CMS diversion strategy (i.e., total diversion, partial diversion or driver advisory/warning), determined based on the type of problem, type of control strategy and traffic flow conditions;
   - CMS event type;
   - Road type; and
   - Location of the CMS (e.g., mainline CMS downstream of first diversion point, mainline CMS upstream of first diversion point and connecting freeways).

The system will then automatically fill in the parameters in the message template structure for each CMS message, such as the number of lanes blocked, location, and direction of the event. A typical message template includes the following text:

Accident {fwy} {dir} at {cross street}
{n} Lanes Blocked
Estimated Clearance Time: {time}

When a new event/incident response plan conflicts with a currently implemented response plan, then the event with the longest estimated clearance time is automatically selected for display on the CMS.

As the final part of the system-generated response plan for incidents, the system will script a brief description of the event details that can be disseminated to the ATIS web page.

3.2.3 User Experience

The Caltrans experience with the event management subsystem has been reported by the system integrator as follows:

- The expert system performs well in generating response plans.
- For an extension of the system to another new geographical area, the development of new system-generated response plans can potentially be quicker and less labour intensive than the development of pre-defined response plans.
    - How to effectively use the expert system, however, is difficult to learn and to use; traffic engineers must work closely with software programmers to effectively translate the traffic engineering rules into program code, and software programmers must know object oriented design programming.
    - There is also a greater effort involved in testing new system-generated response plans (compared to pre-defined response plans) to ensure proper responses for various traffic scenarios.

3.3 Illinois Design

3.3.1 System Background

In 2003, the Illinois State Toll Highway Authority (ISTHA) launched its Traffic and Incident Management System (TIMS), which has been designed to share travel information and reduce delays caused by incidents on its toll highway network. The network has 274 miles (441 km) of toll road, with four interstate toll highways. These highways also interconnect with Illinois expressways to and from Chicago.

TIMS is integrated with the Gary-Chicago-Milwaukee (GCM) Gateway hub as a part of the GCM Corridor Program Plan, and centralizes roadway information from the electronic toll collection system, system-wide weather sensors, computer-aided dispatch (CAD) for tollway maintenance and Illinois State Police, and motorists' phone calls via *999. System operators also monitor approximately 120 CCTV surveillance cameras.

Currently, TIMS has eight CMS's, with four more to be installed soon, and a total of 34 CMS's planned to be installed by 2005. The system includes a message event management and response plan subsystem to assist the operation of the system.

3.3.2 System Description

a. Design Approach

This system design employs a program method in which a hard-coded program is used to generate response plans according to a pre-defined set of rules. Based on the event/incident details, the system uses a rule set to perform sign selection and an event matrix for sign message selection.

Whenever the system is expanded, new rules are not usually required; users only need to add new CMSs into the configuration and define the attributes for each new CMS. The existing rule set will then search for appropriate CMS's and messages for display.

b. Detail Description

The system comprises the following components:

- An event scenario matrix;
- A message template;
- A sign selection database;
- A message library; and
- A response plan library.

The event scenario matrix is used for inputting the following incident details:

- Event type (i.e., accident, debris, stall, roadwork or unknown);
- Location (i.e., mainline lane, exit ramp, toll plaza or connectors);
- Lane affected (i.e., all, some, off-road or unknown);
- Impact (i.e., high full closure, high, moderate or low); and
- Diversion (i.e., yes or no).

For each event scenario, a message template is prepared. Many event scenarios use the same template. A message template consists of fixed phrases and variables; for example, a template can be:

{dir} {fwy}
ACCIDENT {mi} AHEAD
{lanes} {l/r} LANE {s} BLOCKED

The variables used in the templates are explained in Table A3.1.

Table A3.1 – Definition of Message Template Variables

Variables	Replaced with (during process execution)
{fwy}	Highway Name (obtained from location of event)
{dir}	N, S, E & W (obtained from location of event)
{#M}	Number of miles to the event (obtained from the sign location and the event location)
{#m}	Number of miles from a landmark to the event (obtained from Landmarks table and event location)
{#c}	Number of lanes
{side}	Left, right and blanked
{exit}	Exit name
{lndmrk}	Landmark name
{state}	On or Off
{s}	S or blanked
{is/are}	IS or ARE

The sign selection database is used to identify the CMS's to be included in the response plan, based on a pre-defined rule set. The general rules are as follows:

- Number of Critical Interchanges/Decision Points
  - When searching for signs, this value indicates that the search should include all signs upstream of the event through to the sign upstream of the last Critical Interchange/Decision Point.

- Absolute Minimum Distance
    - Signs within this distance to the event are not considered part of the plan; this would be a small value typically set to approximately 0.3 miles (0.483 km).

- Minimum Contiguous Distance
    - On a contiguous freeway (i.e., on the same highway), this represents the minimum distance from the event that should be searched for signs.

- Maximum Contiguous Distance
    - On a contiguous freeway, this represents the maximum distance from the event that should be searched for signs. Note that this distance can override the selection of a Critical Interchange/Decision Point.

- Maximum Additional Non-contiguous Distance
    - The maximum distance to search for signs on a non-contiguous freeway (i.e., on different highway).

The response plan will then be generated according to the following rules:

- Determine the milepost of the event.

- Determine the mileposts for the four distances described in the general rule set above.

- Find the last sign on the contiguous freeway as follows:
    - If the number of Critical Interchanges/Decision Points is zero, then find the first operational sign downstream of the Maximum Contiguous Distance;
    - If the number of Critical Interchanges/Decision Points is greater than 0, then determine the mile post of the first operational sign upstream of the last Critical Interchange /Decision Point included in the plan. If this sign is beyond the Maximum Contiguous Distance, then find the next downstream sign that is within that distance; and
    - If the sign selected is inside the Minimum Contiguous Distance then search upstream for a sign within this distance.

- Include all signs downstream of the last sign, determined above, through to the milepost of the Absolute Minimum Distance. If a Non-contiguous Freeway is included as a Critical Interchange/Decision Point or is between the event and the last sign as chosen above, then include all signs on the Non-contiguous Freeway from the interchange upstream to the Maximum Additional Non-contiguous Distance.

When multiple events/incidents occur in the same or adjacent areas, a priority queue in the CMS sign level defines which message will be currently displayed. The queue structure includes five priorities, from the highest to lowest, as follows:

1. Override: Messages at this level override all other messages
2. Lane-Blocking: Messages generated by Event Management subsystem
3. High (Manual Input): Messages at this level take precedence over Congestion messages but not Lane Blocking Events.
4. Congestion: Messages have higher priority over default messages
5. Default: Default messages have the lowest priority

3.2.3 User Experience

As TIMS was only recently commissioned in 2003, operational experience is not known at this time.

3.4 Hong Kong Design

3.4.1 System Background

As a part of Hong Kong's Airport Core Programme implemented in the mid to late 1990s, which was one of the world's largest infrastructure programs, the Lantau Link, Western Harbour Crossing, and Route 3 (Country Park Section) projects provide crucial links from the Kowloon peninsula, the New Territories and Hong Kong Island to the New Hong Kong Airport. The Western Harbour Crossing is a dual three-lane tunnel with 10 km of associated roads and 17 overpasses. The Lantau Link includes two cable support bridges, a dual three-lane tunnel, and a double-deck suspension bridge with a central span over 1,370 m. The Route 3 roadway includes a 6-km long open roadway and a 4-km long tunnel.

The Hong Kong Transport Department's Traffic Control and Surveillance Systems (TCSS's) for these three highway projects have been built to provide the system operators with an effective tool for expressway traffic management. Traffic management scenarios controlled by each of the these three systems include planned temporary tube/lane closure; schedule contra-flow operations; emergency forced tube/lane closure; caution plan; tunnel emergency plan; overheight vehicle; ad-hoc operation; wind management; adverse weather management, and traffic diversion.

The field equipment used with the traffic management response plans in these systems include lane use/control signals, wig-wags or flashing warning beacons, traffic signals, variable speed limit signs, variable directional signs and changeable message signs.

The response plan design concept of each of these three systems is very similar; they are therefore considered as one system type for the purpose of this investigation.

3.4.2 System Description

a. Design Approach

Due to the complexity of the systems and the large amount of equipment, as well as the large number of traffic management scenarios required to be managed, pre-defined response plans were adopted to assist the operators and ensure consistency of response in implementing traffic control measures.

Two types of response plans are employed: pre-defined table-lookup plans and rule-based algorithm plans. The pre-defined table-lookup plans are designed for specific traffic scenarios; while the algorithm plans are designed to apply rules such as "IF" and "THEN" statements to generate response plans.

These response plans are developed by the traffic engineer in accordance with incident type, severity, location and roadway blockage pattern. It should be noted that the response plans are designed to simultaneously control a variety of equipment, including lane control signs, variable speed limit signs and flashing warning beacons as well as CMS's, in an comprehensive and integrated manner.

It is also noted that new traffic response plans or modification of the existing traffic response plans are needed when the system is expanded.

To minimize operator input error, and allow quick operator response to event/incident situations, all response plans may be selected through a mouse click selection on the graphical user interface.

b. Detail Description

When an incident or event is declared, either manually or from the Automatic Incident Detection (AID) subsystem, the system will prompt the operator to select an appropriate pre-defined response plan according to the following structure:

- Plan group (i.e., non-emergency and emergency);
- Category (i.e., caution, planned lane closure, forced lane stoppage, etc.);
- Control area;

- Current state (i.e., current traffic operational state); and
- Target state (i.e., traffic operational state to be achieved).

The system automatically determines the current traffic state; the operator only needs to select the control area and the target state from a pre-defined list.

Each response plan basically contains the following two parts:

- Plan hierarchical information, such as plan notes, default display area and security class for the plans, which are included to assist the operator to select an appropriate plan; and
- Equipment aspect change information for each step.

The input items used to start a table-lookup plan are as follows:

- Plan name;
- Control area; and
- Blockage pattern.

The algorithm based response plans require the selection of the following parameters (i.e., generally incident details) to start the plan:

- The lane number;
- The gantry nearest the incident;
- The upstream gantry where the traffic impact ends;
- The blockage pattern of the lanes; and
- Whether the traffic is required to merge left or merge right.

After a response plan is selected, the system then leads the operator through the response plan implementation in a step-by-step manner. In each step, two graphic windows display the current and the proposed signal conditions of the roadway, and a plan execution panel prompts the operator for confirmation of that step. The operator is allowed to change any proposed signal conditions before implementing the next step of the response plan.

When multiple events/incidents occur in the same or adjacent areas, the system will not automatically determine which message is to be displayed when more than one message is required to be displayed on the same CMS. The operator has to decide which message has the higher priority between the current message and the proposed message.

c. Other Special Features

A response plan editor is provided for the traffic engineer to create and update response plans in a logical "English-like" language. For instance, the command "Control LUS[2] at F8 → RedCross" in the response plan means "Changing the lane use signal on Lane 2 at Gantry F8 to a red cross". This language is also designed to follow the human reasoning process. A signal group concept is also used to define the start and end location of the signals. For example, the following commands may be used "Control LUS from M1a to M1c → RedCross" or "Control LUS from M1a for 2 km upstream".

3.4.3 User Experience

Experience with Hong Kong's response plan management system design has been reported by the system integrator as follows:

- The development of the response plans, in particular for the initial system commissioning, but also for any expansion and/or modification of the system, is a very labour intensive and time consuming task. The larger the roadway network, the greater is the number of response plans required and hence the greater the effort. Furthermore, when new equipment is installed or any equipment is relocated, every affected response plan has to be reviewed, modified where necessary, and tested.

3.5 Taiwan Design

3.5.1 System Background

The Taiwan Freeway Bureau (TFB) operates a number of ATMS's across Taiwan. Many of these ATMS's manage freeways in both urban and rural areas in a network topology that covers thousands of kilometres, and in most cases include tunnels. The design concepts of several newly built systems are very similar. As a typical example, this section reviews the South 2nd Freeway Section ATMS. The South 2nd Freeway Section ATMS monitors a distance of over 235 km within the southern freeway network. The system includes over 140 CMS's, over 290 vehicle detector stations (VDS), 40 Lane Control Signals (LCS), 140 Changeable Speed Limit Signs (CSLS), 80 CCTV surveillance cameras, and various weather monitoring equipment (e.g., for fog, rain and wind). The CMS's used in the systems are located in critical diversion points.

Besides signing for traffic incidents and conditions, CMS messages also address inclement weather, toxic substances within tunnel, landslides, etc.

3.5.2 System Description

a. Design Approach

In consideration of the extensive response plan generation effort required when the ATMS freeway coverage is extended, a rule-base expert system response plan methodology has been adapted by TFB's traffic engineers for response plan generation.

Rules are established to sign traffic incidents or conditions using the incident/event condition and the relative positions and distances of each CMS sign to the incident/event location. For example, the message immediately upstream of an incident may say "All lanes blocked 1.5 km ahead due to accident", while the second upstream sign may say "All lanes blocked 3.5 km ahead due to accident".

The system employs an expert system inference engine developed in C-Language Integration Production System (CLIPS) to implement the rule-based traffic response plans. The expert system is built based on the following terms: facts, rules, conditions and actions. The facts are event attributes such as incident type, traffic condition, roadway geometry, etc. The rules define how the expert system reacts to the facts. Each rule consists of a set of conditions and a set of actions. The actions are carried out only when the conditions are met.

When the system is expanded, no new rules are required. The modification only involves the re-configuration of the equipment relationship database and the generation of new traffic response plans in the expert system library.

b. Detail Description

The CMS message generation rules identify what CMS's are to be used based on their relative positions to the incident location, event type, roadway geometry, and other event attributes such as blockage pattern and/or traffic congestion level. The rules also identify the text to be used on each sign based on relative distance, incident type, incident condition and incident severity. To provide maximum flexibility in applying the rules, specific location information within the message is avoided in favour of the relative distance from the incident location.

For example, assume that a collision blocks the middle lane and the right-hand lane among three lanes, and one person is injured. The facts of this event are determined as accident (event type), thee lanes (roadway geometry), and two lanes blocked (blockage pattern). These facts will be used to match the specific conditions designed for each of the various rules.

Two separate sets of rules are pre-defined; one for selecting the signs to be used, and one for suggesting the appropriate messages to be displayed. Continuing the above example:

- If the roadway geometry is three lanes and the number of blocked lanes is two lanes, then select a sign on the mainline located before the first upstream interchange, any signs on the mainline between this sign and the accident, and signs located before ramps of the first upstream interchange.

- Advisory message templates are selected based on traffic congestion level, traffic impact, and roadway type (i.e., mainline, ramp, or another freeway). The selected templates include variable contents like {distance to the event}, {event type}, and {blockage pattern} that can be filled in by the system.

Depending on the user's preference, the expert system can either display the recommended signs and messages to the operators for verification or it can execute them immediately.

The ATMS is designed to handle many different incident types of the same priority, and the rule set include rules for assigning priority for when displaying the message on the CMS's. The determination of priorities among several messages for each CMS is based on incident severity. For multiple events/incidents, messages are queued for each CMS, with each sign displaying the highest priority message. When the highest priority message is removed, the CMS will show the next priority message. CMS messages with equal priority will be queued and displayed on a first-come, first-served basis. CMS message updates of this nature are performed automatically by the system without operator intervention.

3.5.3 User Experience

Experience with Taiwan's response plan management system design has been reported by the TFB traffic engineers as follows:

- With this methodology, the rules used in generating messages often do not need to be modified when highway coverage is extended; the rules will need to be changed only if the highway characteristics are different. Therefore, this methodology saves extensive resources required to generate new response plans when the highway coverage is extended.

- The capability to queue messages of the same priority is an important design consideration, since the ATMS can handle many incidents of the same priority.

3.6 Texas Design

3.6.1 System Background

In the early 1990s, a microcomputer-based, knowledge-based expert system was designed and developed as a research project by the Texas Transportation Institute to provide a methodology to evaluate and improve the decision-making process essential in managing freeway incidents. The Incident Management Expert System (IMES) was designed for offline evaluation of highway traffic control strategies, but is capable of being integrated with online ATMS's. This design has remained as a research result since it was first proposed.

3.6.2 System Description

a. Design Approach

In identifying and responding to an incident on the highway, the decision-making process typically includes the following five steps:

- Incident detection;
- Confirmation;
- Prediction of impact;
- Management; and
- Response.

The Texas design employs an expert system approach to assist traffic engineers to better manage freeway incidents, specifically with respect to incident assessment and response.

This system also introduces several important features, such as a rule editor and an inference engine developed in C-Language Integration Production System (CLIPS 5.1). These features enable IMES to be a reusable and easily maintained system for future system expansion.

b. Detailed Description

The system components include a graphic user interface including a menu selection file and a mouse-supporting function, a rule set, a response file, and the CLIPS expert system building tool.

The graphic user interface assists users in identifying the locations of incidents, selecting incident details such as incident type, time, weather, explosion and temperature, and initiating the help function. The mouse allows users to point at any place on the screen and to select menu items. The method avoids typographical errors and provides a direct control in providing information.

The expert system, CLIPS, is the heart of IMES. It serves as a consultant that helps users make appropriate decisions according to the type of incident. The rule base of CLIPS facilitates automation of the incident management process. CLIPS searches the suitable rule from the pre-defined rule set and generates a corresponding response plan as advice to the users. The rule base is developed in accordance with the last two steps defined in the decision-making process as follows:

- Incident assessment, which considers the following information:
  - The capability of the organization in terms of equipment availability, status and location, and personnel availability;
  - The likely duration of the incident;
  - The potential impact on traffic flow and route, the time of day, and traffic volumes; and
  - The status of the primary route and any possible diversion routes, for consideration of a potential freeway diversion and in releasing traffic information.

- Incident response depends on established local practices and includes such factors as:
  - Personnel and equipment;
  - Real-time motorist information: signs, Highway Advisory Radio (HAR), radio, TV broadcasts;
  - Off-site traffic control for diversion; and
  - Other traffic control strategies.

A rule editor, which uses features of Windows, enable users to easily maintain the rule set. The rule editor allows users to modify rules without having knowledge of CLIPS or programming.

A text editor provides the system with the capability to maintain or expand some system configuration files for menu selections and response. Users can change menu items and responses easily without system recompilation.

This system design does not cover the handling of multiple conditions/ incidents.

3.6.3 User Experience

When it was developed in the early 1990s, the system was considered very advanced in the ATMS field. Although the system was never implemented, the design concept offers the following benefits:

- Rather than memorizing the condition and action items of the rules, users can easily select items from the menu lists. The use of the rule editor reduces the complexity of maintaining IMES. In other words, users' productivity can be improved.

- Users can select items rather than typing them, thus avoiding clerical errors.

- It is not necessary for the user to be a CLIPS expert to maintain the rule base. After the user selects the items, the system automatically generates the corresponding rules. The generated rules are syntactically correct.

- The rule editor is easy to use and learn. The usability of IMES is thus increased.

3.7 UK Design

3.7.1 System Background

The National Driver Information and Control System (NADICS) in Scotland has been developed to provide national control of Scotland's motorway network in west central Scotland. NADICS is integrated with Centrally Integrated Traffic Control (CITRAC), which offers control of urban traffic signals. NADICS and CITRAC are controlled and operated by Glasgow City Council, and co-located at Glasgow National Network Control Centre. Both systems were built in early 1980's.

The objective of NADICS is to develop and operate traffic management measures across the whole of the network to alleviate congestion and to increase the efficiency of use of the existing network. This includes the further development of NADICS to inform the travelling public of traffic and road conditions.

NADICS currently covers approximately 6,000 sq. km and has 94 full function CMS's, 45 single line CMS's (i.e., 1 line of 21 characters – used on M8 Motorway overhead gantries incorporating lane control units), 130 CCTV cameras, and 1170 traffic monitoring sites. The core functions of the system include:

- Network Monitoring: CCTV cameras, loop detectors, incident detection, etc.;
- Traffic Control: overhead lane signals, CITRAC, CMS's and ramp metering; and
- Information Dissemination: CMS's and lane signals.

NADICS contains the following features:

- Single integrated system;
- Multiple functions/responses;
- Multiple users (police, operations, etc.);
- Integrated response capability; and
- Integrated link to CITRAC UTC (urban traffic signal control) system.

3.7.2 System Description

a. Design Approach

In the system, three types of response plans are designed as follows:

Manual plans:	Control room staff set messages manually in accordance with established guidelines.
Pre-defined plans:	Users select from problem (event) lists, and an appropriate pre-prepared signing plan from pre-defined plans is then implemented. Police users can deal with local problems in their areas from a problem list tailored to their needs and control room staff can add strategic signing if necessary. Problem lists for control room strategic signing also include recurring events (e.g., Bridge Closures for high winds). These plans are designed for particular situations
WAAR:	Wide Area Algorithmic Response automatically selects relevant CMS's, constructs legends, and implements signing based on incident details enter by control room staff. No new rules are required for WARR if the system is expanded.

b. Detail Description

The system automatically assesses the impacts of incidents and then suggests response plans according to the WAAR. The system also automatically tracks responses and removes responses when incidents are cleared up.

The event types that the system responds to include 9 categories and 57 event types. Table A3.2 summarizes the event categories and types.

Table A3.2 Event Categories and Types

Event Category	Event type
Closure	Road Closure, Closed, Off Slip Closed, No exit, Closed to High Sided Vehicles and Caravans, Closed to High Sided Vehicles, Closed to High Vehicles, Now Open, Open, Opening, Will Open
Accident	Accident
Breakdown	Breakdown
Hazard	Abnormal Load, Shed Load, Animals, Debris, Floods, Flooding, Pedestrians, Pedestrian, Obstruction, Incident Ahead, Fluid Spillage

Weather	Fog, Low Temperature, Low Temp, Surface Water, Snow, High Winds
Roadwork	Roadworks, Works, Work, Major Works
Queue	Queue, Queues, Queuing Traffic
Ferry	Ferry, Ferry Service, Off Until
Event	For example, T in the Park, T in Park, Royal Highland Show, Knockhill Event, Raf Leuchers, East Fortune Air Show, Air Show, etc.

The generation of traffic responses by WAAR involves two tasks: construct 'legends' or messages, and select relevant signs. Details concerning these two tasks are described as follows:

The messages are composed from word lists approved by the Scottish Executive. The message construction (with the exception of safety message and park and ride schemes, which are individually defined) is based on the Problem Location Effect Guidance (PLEG) structure, with the additional element of Time Period used for Pre-defined legends. The PLEG structure is as follows:

- Problem – Legends (messages) must contain the nature of the problem and the route affected.
- Location – Legends must contain the location of the problem; depending on the configuration of a CMS and the number of characters available, it may be necessary to use an abbreviated version of location.
- Effect – Delay information should be included, if known, but the level of detail is dependent on the quality of information available.
- Guidance – Information should be included if possible. In the case of Hazard problem, safety advice is given.

An example of legend (message) construction is shown as follows:

ROADWORKS M9(N)
AFTER
J10 CRAIGFORTH
(free line)

WAAR will construct the message to suit different CMS formats (e.g., 4 lines of 15 characters, 3 lines of 18 characters) and leave the last line free to allow for manual addition of delay information or guidance.

WAAR will select the relative CMS's by "tracing" backward from the affected link along the encoded link network and find CMS's which are "attached" to particular links. The distance travelled and direction of this "tracing" is controlled by various rules from the link network and the event/incident details. The link network rules include:

- The tracing will not find a link in the opposite direction of the affected link. It should be noted that this rule can be overridden, if necessary, by the following methods:
  - Encoding "ghost links" of a suitable direction to jump past a problem area and continue the tracing.
  - 'Associating" specific CMS's with a particular link, which results in CMS's being selected which would not be found in the tracing.

- The tracing can be stopped by using "stop points" and "pass through points".

The event/incident detail rules use incident type and anticipated duration to limit the distance traced by WARR. Each link encoded in the network has a measure distance, which is added to a running total as WAAR traces the route. The tracing is stopped when the accumulated distance reaches its limit. The distance limits, in metres, are listed in Table A3.3.

Table A3.3 Distance Limits

Incident Type	
Closure	100,000 metres
Accident	80,000 metres
Road Works	80,000 metres
Others	60,000 metres
Anticipated Duration	
15 minutes	20,000 metres
30 minutes	40,000 metres
45 minutes	60,000 metres
60 minutes	80,000 metres (or incident type limit)
90 minutes	100,000 metres (or incident type limit)

Note: The anticipated durations for the incident type are "indefinitely".

3.7.3 User Experience

Experience with the response plan generation system design has been reported by the traffic officer at the Glasgow National Network Control Centre as follows:

- The main advantage of this system is realized when a new CMS is installed on the road network. The CMS is just simply added to the system and to the link that matches its geographical location. The CMS will then be found by the WARR and included in any signing resulting from an incident. This is an advantage over pre-defined plans, which are required to be edited every time a new CMS comes on-line.

3.8 Summary of Selected System Designs

In the development of an intelligent sign management system, the objectives for new CMS response plan strategies include the following:

- Manage "multiple conditions/incidents" at the same time, including travel time, road conditions, special situations, incidents and safety;
- Automatic resolution of sign message conflicts without operator involvement on what to do;
- Manage a network of freeways;
- Use multi-phased messages;
- Vary strategies by "time-of-day / day-of-week" (TOD/DOW) or level of congestion; and
- Require no response plan changes with the addition of new signs.

Table A3.4 summarizes how the seven reviewed system designs address each of these six objectives.

Table A3.4 Summary of Selected System Designs

Objectives **Designs**	Manage multiple conditions/ incidents at the same time	Automatic resolution of sign message conflicts	Manage a network of freeways	Use multi-phased messages	Vary strategies by TOD/DOW or level of congestion	Require no plan changes with new signs
MTO Design	+	-	+	-	-	-
California Design	+	+	+	-	+	+
Illinois Design	+	+	+	-	-	+
Hong Kong Design	+	-	-	-	-	-
Taiwan Design	+	+	+	+	+	+
Texas Design	-	-	-	-	+	-
UK Design	+	-	+	-	-	-

Legend: + : With the function

- : Without the function

4.0 Analysis of Design Approaches

4.1 Methodology

Each of the systems reviewed in the previous section has its own strengths and weaknesses, as well as different development background. For the purposes of this project, it is not appropriate to rank the systems as individual systems; it will be more appropriate to examine the systems on a higher concept level such as design approach. A particular system design approach generally provides design directions that determine system structures as well as traffic operational concepts. In this respect, the identified seven systems have been categorized into different design approaches for analysis under several essential evaluation criteria.

The categorization of the reviewed systems, the items identified for evaluation, and the analysis of the respective approaches are addressed in the following sections.

4.2 Categorization

From the review of the seven identified systems, they can be categorized into three different approaches:

- Table-lookup;
- Program; and
- Expert system.

The table-lookup type pre-defines a set of response plans based on event/incident type, severity, location, and blockage pattern. The operators have to initiate an appropriate response plan based on correct incident information and their proper assessment of the incident severity and traffic impact. The reviewed systems that have employed this approach include the MTO design and the Hong Kong design.

The program type uses logical rules defined from local practices and then hard codes them into a program. The logical rules generally address equipment selection, message display composition and notification of appropriate incident response agencies. An operator only needs to input details of a confirmed incident (e.g., event/incident type, location, and blockage pattern); the program will automatically assess the traffic impact and generate response plans based on the embedded rules. The reviewed systems that have employed this approach are the Illinois and UK designs.

The expert system type also uses a rule base; one that is coded into an expert system. The operation of this type is very similar to that of the program type.

The expert system generally consists of a knowledge base and an interference engine. The knowledge base stores rules that consist of a collection of pre-conditions and post-conditions. The rule pre-conditions lists the conditions to be matched with the event/incident facts, and the post-conditions are the appropriate actions to be taken. An operator only inputs incident details; the expert system translates them into facts, automatically finds a rule based on those facts, and generates a response plan. The reviewed systems that have employed this approach include the California, Taiwan and Texas designs.

4.3 Evaluation Items

The evaluation of the reviewed systems was considered under the following five major categories:

- Automation;
- Flexibility;
- Comprehension;
- Expandability; and
- Development effort.

In the automation category, two items were considered for evaluation:

- Automatic traffic impact assessment; and
- Automatic response plan suggestion.

In the flexibility category, four items were considered:

- Equipment and personnel availability;
- Equipment relocation;
- Local practice changes; and
- Technology transfer.

In the comprehension category, two items were considered:

- Learning curve; and
- Staff experience.

In the expandability category, two items were considered:

- New control areas or equipment; and
- New rules.

In the development effort category, two items were considered:

- System development; and
- Testing of plans.

4.4 Analysis of Three Typical Design Approaches

The analysis for the three types of design approaches is summarized in Table A4.1 and addressed in the following subsections.

Table A4.1 Summary on Analysis of System Design Approaches

Design Approaches	Table-Lookup	Program	Expert System
Automation			
Automatic traffic impact assessment	-	+	+
Automatic response plan suggestion	-	+	+
Flexibility			
Equipment and personnel availability	-	+	+
Equipment relocation	-	+	+
Local practice changes	-	-	+/-
Technology transfer	-	-	+/-
Comprehension			
Learning curve	+	+/-	-
Staff experience	+/-	+	+
Expandability			
New control areas and/or equipment	-	+	+
New rules	-	+	+
Development Effort			
System development	+	-	-
Testing of plans	+	-	-

Legend:
+ : Requirement is highly satisfied
- : Requirement is not satisfied
+/- : Requirement is somewhat satisfied

4.4.1 Automation

In this category, automatic traffic impact assessment and automatic response plan suggestion capabilities are considered. Such automated operations can minimise the number of times that operators are required to make a judgment decision and ensure consistency of response among individual operators. Inconsistent or incorrect assessments and/or responses can bring the system into disrepute and cause confusion among motorists as well as the different incident response agencies. Such problems are unnecessary and can be resolved through modern technology. Therefore, these two items were used to evaluate the three identified design approaches with respect to automation.

The table-lookup type generally does not have automatic traffic impact assessment and automatic response plan suggestion. The operator must make a judgement in assessing the details of the event/incident and selecting the appropriate pre-defined response plan.

The program type and the expert system type reviewed in this study have both of these features. Under this category, the program and expert system types perform better than the table-lookup type.

4.4.2 Flexibility

Changes to response plans are often required to reflect current equipment and personnel availability, equipment relocations, local practice changes, and new technology implementations. With respect to equipment and personnel availability, the system can provide the flexibility to temporarily substitute alternative equipment when desired equipment has failed. Other more permanent changes, like equipment relocation and location practice changes, are also situations that most systems encounter when they are in operation. Technology transfer and the ability to continuously upgrade the system is also an important issue. The system design can make the modification of response plans in response to such changes either very easy or very difficult. These four items are therefore used to evaluate the flexibility of the identified three design approaches.

The table-lookup type generally lacks flexibility in equipment and personnel availability, equipment relocation, local practice changes, and technology transfer. Any modifications to the response plans require manual adjustment, which is usually very time consuming and potentially error prone.

The program type only lacks the flexibility in local practice changes and technology transfer, because all rules are hard coded into the program. To modify the program typically requires the original system developer or someone with knowledge of the specific program skill and familiarity with the design, and the work required for the modification can be major.

The expert system type is more flexible than the other two types. Equipment and personnel availability, and equipment relocation might not require any changes to the system; changes to local practices and technology transfer may need someone with the knowledge of using the expert system to implement the changes, but the work required for the modification is usually only minor.

4.4.3 Comprehension

In the comprehension category, the system learning curve and staff experience required to operate and maintain the system are considered. The amount of time required for both the developers and the operators to first learn how the system operates is an important consideration in the success of a system – if the system is very difficult to learn, it may not be used to its maximum capability. Staff experience required to effectively operate and manage the system is also an important factor to be considered. For example, are experienced operation staff required to make judgments on the selection and implementation of appropriate response plans?

For the table-lookup type, the effort spent in learning the system is less than the other two types. All response plans are pre-defined and users can easily understand the structure of the traffic plans. However, staff experience is highly recommended for the successful operation of a system.

For the program and expert system types, the effort required to learn the system is much higher than for the table-lookup type. Developer's program skills and experiences in analyzing operation practices into rule-based are essential when designing systems in these two types. Operator experience is not a critical issue for these two types, since traffic impact assessment and response plan suggestion can be automated.

4.4.4 Expandability

This category considers the effort spent in adding new response plans and/or modifying existing response plans when a new control area and/or new equipment is added to the system, and when a new rule is introduced to the system.

With the table-lookup type, response plans are not easy to modify when a new control area and/or new equipment is added, since all the plans are fixed. All response plans have to be reviewed whenever a new rule is introduced.

The program and the expert system types are generally easier to expand and to add a new rule, because they are rule-based.

4.4.5 Development Effort

Under this category, the effort required in designing and developing the system, as well as the effort required in developing and testing the response plans to ensure proper operation, are considered.

The design of a table-lookup type system is relatively simple; hence, the development effort for such a system is expected to be much less than for program or system expert type systems. While the development and testing of response plans for this system type is labour intensive, the total effort required can be accurately estimated and managed.

In contrast, the development effort for implementing a program or expert system type system is expected to be much greater than for a table-lookup type system.

In particular, the testing of the system rules is always a major concern of the traffic engineers, who usually require numerous testing scenarios be conducted in order to test the full range of possibilities and identify any potential deficiency in the rules.

5.0 Conclusions

The conclusions are summarized as follows:

- From the evaluation of the identified three general design approaches, the rule based program and expert system design approaches best satisfied the evaluation items.
  - The expert system approach performs slightly better than the program approach; however, the learning curve for the expert system type is typically much longer and more difficult, which potentially could negatively impact on the successful completion of the system. More investigation on the usage of expert systems is required.
- A rule-based design approach is therefore recommended for the generation of response plans for the proposed intelligent sign management system.
- The review process provided constructive insights into other system designs. Several features of the seven reviewed systems are recommended for consideration in the proposed intelligent sign management system. These features include the following functions intended to assist operators in using and operating the system:
  - Automatic assessment of traffic impact based on the incident details – the design of the proposed intelligent sign management system should include rules for the traffic impact assessment process; rules that would include such factors as incident type, number of lanes blocked, estimated clearance time, and others;
  - Automatic suggestion of proper response plan based on the traffic impact – the design of the proposed system should include rules for the response plan suggestion process; rules that would include such factors as incident type, traffic impact, roadway type, etc.;
  - Verification of equipment and personnel availability;
  - Easy editing of the rule base, without the user requiring detailed knowledge of the expert system or program languages; and
  - Capability to manually modify a system-recommended response plan.
- The proposed intelligent sign management system should be flexible to accept different response plan design criteria in response to different local practices. This will enable the system technology to be portable to different locations around the world.

These conclusions will be used as foundation for the tasks to be conducted under Stage 2, in which an innovative intelligent sign management system will be further developed and designed.

Bibliography

Advanced Transportation Management System Traffic Engineer's Manual, Caltrans, 2001.

Boston Central Artery/Tunnel Traffic Management Using An Expert System, Robert Stack, Transdyn Controls, Inc., 1997.

Development of Prototype Knowledge-based Expert System for Managing Congestion on Massachusetts Turnpike, Arti Gupta, Victor J. Maslanka and Gary S. Spring, Transportation Research Record 1358, Page 60 – 6, 1992.

Expert System and Case-based Reasoning for ITS Decision Website, Asad Khattak and Joy Dahlgren, PATH Annual Meeting, October 2002.

Freeway Incident Management Expert System Design, Edmond Chin-Ping Chang and Kunhuang Huarng, Transportation Research Record 1399, Page 36 – 44, 1993.

Freeway Traffic Control and Management in Hong Kong, Simon H. Lau and Richard Chylinski, 5th World Congress on Intelligent Transportation Systems, 1998.

Human Factors In Traffic Management Centers: A Literature Review, Cristopher Nowakowaski, Paul Green and Mark Kojima, UMTRI-99-5, DOTF, 1999.

Intelligent Traffic Management Models, Heribert Kirschfink, Josefa Hernandez, Marco Boero and Momatec GmbH, Technical University of Madrid, ESIT 2000, Aachen, Germany, 2000.

Orbit: Transport Solutions Around London – State of the Art Methods Report, KBR, 2002.

Real-time Expert System Approach to Freeway Incident Management, Stephen G. Ritchie and Neil A. Prosser, Transportation Research Record 1320, Page 7 – 16, 1991.

Real-time Traffic Management Through Knowledge-based Models, Josefa Hernandez, Jose Cuena and Martin Molina, Technical University of Madrid.

Requirements Specification for DMS Message Optimization Tool (MOST), Paul Davis, Sangita SunKari, Conrad Dudek and Kavin Balke, FHWA/TX-03/4023-2, 2002.

Traffic Control System Specification for Taiwan 2nd Freeway Ko-Kung to Lin-Bing Section, Taiwan Area National Expressway Engineering Bureau (TANEEB), 1996.

Training Material for Illinois State Toll Highway Traffic and Incident Management System (TIMS) DMS Event Management and Response Plans, 2003.

UTMC02: Traffic Management Across Jurisdictional boundary – System Architecture and Proposals for Demonstration, K. Wood, A. Mankenzie, H. Morton, and the UTMC02 consortium, 1999.

APPENDIX B

Technical Report on New CMS Message Generation Techniques

TABLE OF CONTENTS

Page

1.0 Introduction 1
  1.1 Purpose 1
  1.2 Document Organization 1
2.0 Requirements 2
  2.1 Basic Requirements 2
  2.2 Recommendations 2
3.0 Traffic Response Principles 3
  3.1 Event Assessment 3
    3.1.1 Event Categorization 3
    3.1.2 Severity 4
    3.1.3 Diversion Strategy 5
  3.2 Traffic Response Strategy 5
    3.2.1 Response Strategies 5
    3.2.2 Control Strategy Identification 6
  3.3 Operation Consideration 7
    3.3.1 Event Combination 7
    3.3.2 Highway Network 7
    3.3.3 Sign Size 7
    3.3.4 Message Composition Structure 7
    3.3.5 Multiple Messages 8
4.0 System Design 9
  4.1 Methodology 9
  4.2 System Structure 9
5.0 System Component Analysis 11
  5.1 Processes 11
    5.1.1 Event Detail Input 11
    5.1.2 Event Assessment 11
    5.1.3 Sign Selection 12
    5.1.4 Message Determination 13
  5.2 Objects 14
6.0 Development of Response Plan Rules 16
  6.1 Event Input Requirements 16
  6.2 Rules for Event Assessment 17
    6.2.1 Event Categorization 17
    6.2.2 Severity 18
    6.2.3 Diversion 20
  6.3 Rules for Sign Selection 20
    6.3.1 Rules for Determining Signing Extent 20
    6.3.2 Rules for Selecting Signs To Be Activated 21
    6.3.3 Rules for Handling Sign Availability 21

6.4 Rules for Message Determination 22
  6.4.1 FELG Phrase Library 22
  6.4.2 Rules for Composing Messages 23
  6.4.3 Rules for Handing Multiple Messages 25
7.0 Additional Functional Requirements 27

LIST OF TABLES

Table B3.1 Control Strategy Identification
Table B6.1 Rules for Identifying the Event Category
Table B6.2 Rules for Determining Congestion Severity Level
Table B6.3 Criteria for Determining Current Traffic Situation
Table B6.4 Rules for Determining Diversion Strategy
Table B6.5 Signing Extent for Incident Management Strategy
Table B6.6 Rules for Selecting Signs To Be Activated
Table B6.7 Rules for Handling Sign Availability
Table B6.8 FELG Phrase Library
Table B6.9 Definition of Location Phrases
Table B6.10 Rules for Status Review
Table B6.11 Rules for Message Composition
Table B6.12 Rules for Handing Multiple Messages
Table B6.13 Three Message Templates for Combining Messages

LIST OF FIGURES

Figure B4.1 System Structure
Figure B5.1 Example of Sign Selection
Figure B6.1 Traffic Impact Determination Flowchart

ACRONYMS

The acronyms used in this document are defined as follows:

ATMS	Advanced Traffic Management System
CMS	Changeable Message Sign
TOD/DOW	Time-of-Day/Day-of-Week
FEG	Facility, Event, and Guidance message format
FELG	Facility, Event, Location and Guidance message format
FEL	Facility, Event and Location message format

1.0 Introduction

1.1 Purpose

This report presents the design details for the new CMS Message Generation techniques from the sign management knowledge database determination and the artificial intelligent software design. The main objective of these tasks is to determine an appropriate design that can meet the requirements of the intelligent Changeable Message Sign (CMS) message manager. The system design includes descriptions of the system structure and the detailed specification of all functionalities. The proposed design described in this report will be used as the guideline for the system implementation.

1.2 Document Organization

This report is divided into seven sections as follows:

1. Introduction
   The purpose and structure of this report are addressed.

2. Requirements
   The requirements and conclusions are reviewed in this section to demonstrate the basic functions that the intelligent sign management system shall have.

3. Traffic Response Principles
   This section explains the traffic response principles. The contents include event assessment, response strategy identification and traffic response guidelines.

4. System Design
   The system design methodology and system structure are described.

5. System Component Analysis
   This section explains the considerations for each process and properties for each defined object.

6. Development of Response Plans Rules
   This section describes details of rules for developing traffic response plans.

7. System Design Functional Requirements
   The section lists system design functional requirements based on the project objectives as well as the determined rules.

2.0 Requirements

The section reviews the basic requirements and conclusions from the report "Technical Report on Existing CMS Message Generation Techniques".

2.1 Basic Requirements

In the development of an intelligent sign management system, the objectives for new CMS response plan strategies include the following:

1. Manage "multiple conditions/incidents" at the same time, including travel time, road conditions, special situations, incidents and safety;
2. Automatic resolution of sign message conflicts without operator involvement on what to do;
3. Manage a network of freeways;
4. Use multi-phased messages;
5. Vary strategies by "time-of-day / day-of-week" (TOD/DOW) or level of congestion; and
6. Require no response plan changes with the addition of new signs.

2.2 Recommendations

1. Rule-based design approach is recommended for the generation of traffic response plans for the proposed intelligent sign management system.

2. Several features of the seven reviewed systems are recommended for consideration in the proposed intelligent sign management system. These features include the following functions intended to assist operators in using and operating the system:

    - Automatic assessment of traffic impact based on the incident details – the design of the proposed intelligent sign management system should include rules for the traffic impact assessment process; rules that would include such factors as incident type, number of lanes blocked, estimated clearance time, and others;

    - Automatic suggestion of proper response plan based on the traffic impact – the design of the proposed system should include rules for the response plan suggestion process; rules that would driven by such factors as incident type, traffic impact, roadway type, etc.;

    - Verification of equipment availability;

    - Easy editing of the rule base, without the user requiring detailed knowledge of the expert systems or program languages; and

    - Capability of manually modifying or overriding a system-recommended response plan.

3.0 Traffic Response Principles

Traffic response is a combination of actions in response to the current roadway conditions. The logic of developing traffic responses is very similar to the human reasoning process. This process will cover three aspects: event assessment, traffic response strategy identification and operational consideration. The details concerning the conceptual guidelines of traffic response are addressed respectively in the following subsections.

3.1 Event Assessment

Event assessment is the first step in the human reasoning process. It evaluates impacts of an event on the current traffic operation. The assessment items include event categorization, severity, and diversion strategy. The assessment results provide a good direction in identifying appropriate traffic control strategies and response messages. The details concerning the event assessment are as follows:

3.1.1 Event Categorization

There are many types of events. Each type has its own nature and requires different control strategies. The events usually can be categorized into six groups:

1.	Lane-blocked incident type:	Events, such as a collision or stalled vehicle, in this type usually are unplanned and block the lanes at one point on the roadway.
2.	Congestion type:	Events in this type usually are unplanned and affect all lanes in a section of the roadway.
3.	Roadwork type:	Events in this type usually are planned in advance and affect some lanes in a section of the roadway.
4.	Road condition type:	Events such as rain, snow or wind in this type are unplanned and affect driving conditions in a bigger stretch of the roadway.
5.	Special event type:	Events in this type usually are not planned.
6.	Safety type:	Messages are used to promote highway safety.

Please note that the design of responses for special event and safety type messages are not included in this document because they usually depend on the regional traffic management needs.

3.1.2 Severity

Severity is an index to describe the impact of events. Because the nature of each event type is different, the method to assess the severity for each event type is different. It is not necessary to obtain severity for the special event and safety type messages above because they do not affect the normal traffic operation or create dangerous driving conditions for drivers.

1. **Congestion Type**

   The severity of the event in the congestion type is assessed based on travel speed and queue length. The travel speed is the main factor to determine severity in most ATMS operations. Queue length is occasionally applied to determine severity because it only describes extreme traffic conditions.

2. **Road Condition Type**

   The severity of the event in the road condition type is assessed based on measurements from the rain, fog, wind, or other environmental detectors. Determining the severity level for these events mainly rely on the location practices.

3. **Lane-blocked Incident Type and Roadwork Type**

   The severity of the event in either lane-blocked incident type or roadwork type is assessed based on roadway geometry, current traffic condition and clearance time because of the similarity of both types of events. The three factors are further explained as follows:

   - **Roadway Geometry**
     Roadway geometry is a general term. It includes roadway type and blockage pattern. Identifying the roadway type where the event occurs is important to determine the severity of the event. The roadway types usually include mainline lanes, ramps, connecting freeway or arterials. The blockage pattern is used to describe the lane-blocked condition. For example, "XX↑" means two right lanes of the three traveling lanes are blocked. Only events in the incident lane-blocked type or roadwork type require the lane blockage pattern information.

   - **Current Traffic Condition**
     The current traffic condition is another important index to determine the severity of the event. Similar events occurring in different traffic conditions (e.g. heavy traffic or light traffic) cause different severity levels. Since the relationships between traffic volumes and occupancies can be drawn like a polynomial curve line, a traffic volume can represent two different occupancies. Therefore, the traffic condition shall be examined by checking both traffic volumes and occupancies.

- **Clearance Time**
  The clearance times for each event is suggested based on the current highway operation experiences. The clearance time is also used to determine the severity of the event.

3.1.3 Diversion Strategy

The diversion strategy is assessed under two situations. Situation one checks the blockage pattern of the lane-blocked incident event and decides the diversion strategy (total diversion, partial diversion or no diversion). The second situation checks the congestion severity levels from two parallel roadways for congestion events and decides the diversion strategy (partial diversion or no diversion). The diversion strategy is used in selecting an appropriate message for the event.

3.2 Traffic Response Strategy

Five traffic response strategies are summarized from most ATMS operations. These traffic response strategies are commonly used in response to different types of events. The details are addressed as follows:

3.2.1 Response Strategies

1. **Traveller Information**

   The traveller information provides the traffic conditions of the roadway sections through CMS signs to help drivers traveling from upstream to avoid unsafe driving conditions and in selecting their traveling routes. The information usually includes the congestion level, travel time, incidents, weather conditions, planned roadwork and other events. The CMS signs are usually located before the diversion points in the highway network. The general principle for the CMS sign selection (i.e. how many upstream diversion points or how long the upstream traffic is affected) is usually based on the severity of event.

2. **Speed Control**

   When an event causes dangerous driving conditions such as lanes blocked or queues, controlling the speed limit approaching to the event is important to enhance safety. The speed control adjusts several upstream speed limit signs and the speed limits of these signs are gradually reduced from a higher speed to a lower speed (e.g., 80 km/h, 60 km/h, 40 km/h). When the event is cleared, the speed limits are changed back to the normal operation.

3. **Lane Usage Control**

When an event causes dangerous driving conditions such as lanes blocked or closed, lane usage control is applied to direct traffic to avoid the affected lanes. The sign used in this control is called the lane control sign. Usually each lane has a sign at each location. Each sign has different aspects like down green arrow, red cross, slanting arrow right or slanting arrow left to direct the traffic. When an event occurs, the lane usage control provides a merging direction (i.e., slanting arrow right if a left lane is blocked or closed) before the event and the lane closure indication (down green arrow for the normal operation lane and red cross for the blocked lane) at the event location and beyond to drivers. If the more than one lane is blocked, the lane usage control closes the slowest lane first and then the other lanes. The merging directions are the same and staggered.

4. **Ramp Metering System**

When an event causes roadway capacity reduction or the traffic demand is high, a ramp metering system is usually applied to regulate the traffic flows entering the highway. The control increases the throughput and travel speed on the highway. Installing ramp metering equipments to each interchange in a metropolitan area is usually recommended so that they can effectively improve traffic conditions. For rural areas, the ramp metering installation for the surge of traffic demand in holidays might be sufficient.

Ramp metering systems might have different traffic control logics including fixed time control, local traffic responsive control, integrated traffic responsive control and adaptive control. These control logics are designed to meet different traffic needs. It is not necessary to have all four logics implemented. The fixed time control only needs time-of-day tables for interchanges. As for the other control logics, the ramp metering system calculates appropriate metering rates to the upstream interchanges based on current traffic data and the capacity reduction caused by an event.

5. **Queue End Warning**

When queues are formed due to events or congestion, queue end warning is applied to warn the approaching traffic. Queue end warning is recommend in areas where the queues might occur and the travel speed is generally high. The system monitors the most updated traffic data and calculates the queue length and location. If queues exist, the system sends a message through upstream CMS signs to warn motorists.

3.2.2 Control Strategy Identification

Table B3.1 lists strategies identified for each event type.

Table B3.1 Control Strategy Identification

Event type	Traveller Information	Speed Control	Lane Usage Control	Ramp Metering System	Queue End Warning
Lane-blocked incident	Y	Y	Y	Y	Y
Congestion	Y	Y	-	Y	Y
Roadwork	Y	Y	Y	Y	Y
Road Condition	Y	Y	-	-	-

Note: Y means recommended for the event type
- means not recommended

3.3 Operation Consideration

After the identification of the traffic strategies, several operation considerations are addressed as follows:

3.3.1 Event Combination

Event combination is considered when two events occur nearby. If the two events are the same event type, they can be combined by changing blockage pattern or affected area. If events are not in the same type, but one event is the result of the other event (e.g. a congestion event can be the result of a vehicle collision), then these two events can be combined.

3.3.2 Highway Network

In most large urban areas, a highway network is quite common rather than a single highway. The traffic operations in the highway network are correlated. It is important to display the traffic conditions of the highway to the drivers on the connecting highway so that they can choose traveling routes better. Therefore, the highway network is taken into consideration when selecting appropriate signs and messages to be displayed.

3.3.3 Sign Size

Sign size is the layout of the sign. It is an important factor while determining CMS sign messages. There are many types of CMS signs as follows:

- Overhead type: 3 X 25 (3 lines, 25 characters each line)
- Cantilever type: 3 X 21 (3 lines, 21 characters each line)
- Portable type: 3 X 12 (3 lines, 12 characters each line)

3.3.4 Message Composition Structure

The message determination process is considered to include two elements: a message phrase library and a set of rules. The message phrase library will be built based on the FELG (i.e. Facility, Event, Location and Guidance) structure.

These phrases are pre-defined in these four categories and are selected by the rules.

3.3.5 Multiple Messages

Multiple phase messages are considered to handle multiple requests on the same sign at the same time. The multiple phase messages check the immediate upstream travel speed to verify the suitability of rotating multiple messages.

Message combination is considered to handle multiple requests on the same sign at the same time. The Message combination checks the event types and verifies the suitability of combining messages.

4.0 System Design

4.1 Methodology

System design usually starts with a high-level conceptual design and proceeds through a process of refinement, verification, implementation and testing. Therefore, determining a good design approach is essential to reduce any impacts caused by any new introduced requirements and to make the system development cost-effective. As modern technology evolves, object-oriented modeling skills are gradually being adapted by system designers and becoming mainstream skills. Therefore, we propose a design flow that relies on abstract object-oriented modeling concepts. Models of this type offer graphical representations to demonstrate the functions and their relationships. These types of concepts will benefit the system verification, and the object nature of the model creates the possibility of design reuse.

4.2 System Structure

As the object-oriented model is chosen for the design concept, the system structure is designed to include objects and processes. The objects are entities controlled with behavioral attributes. And the processes control the behaviors of objects by determining the contents for the behavioral attributes based on a set of rules.

For this project, the event management is a decision-making process. For example, when events occur, proper responses (e.g., Changeable Message Signs) are proposed to cope with the current traffic conditions. Event assessment and event response are two main stages of the decision-making process. The event assessment conducts an evaluation and produces event properties that can be used to initiate proper responses in the event response stage. Then the event response suggests appropriate signs and messages based on the event properties. Two tasks are involved: sign selection and message determination. The event, event properties, available sign equipment and selected equipment are the entities to be controlled, and are defined as objects. The event details input, event assessment, sign selection and message determination that change the object attributes are defined as processes. The four objects and four processes are therefore as follows:

Objects:
- Event details
- Event properties
- Tentative equipment
- Equipment

Processes:
- Event details input (user input)
- Event Assessment (rule-based)
- Sign Selection (rule-based)
- Message determination (rule-based)

In addition, operator intervention is also considered in the decision-making process. Before the responses are implemented, the operators shall be able to review the responses and change event inputs.

The procedure flow among objects and processes is described in Figure B4.1.

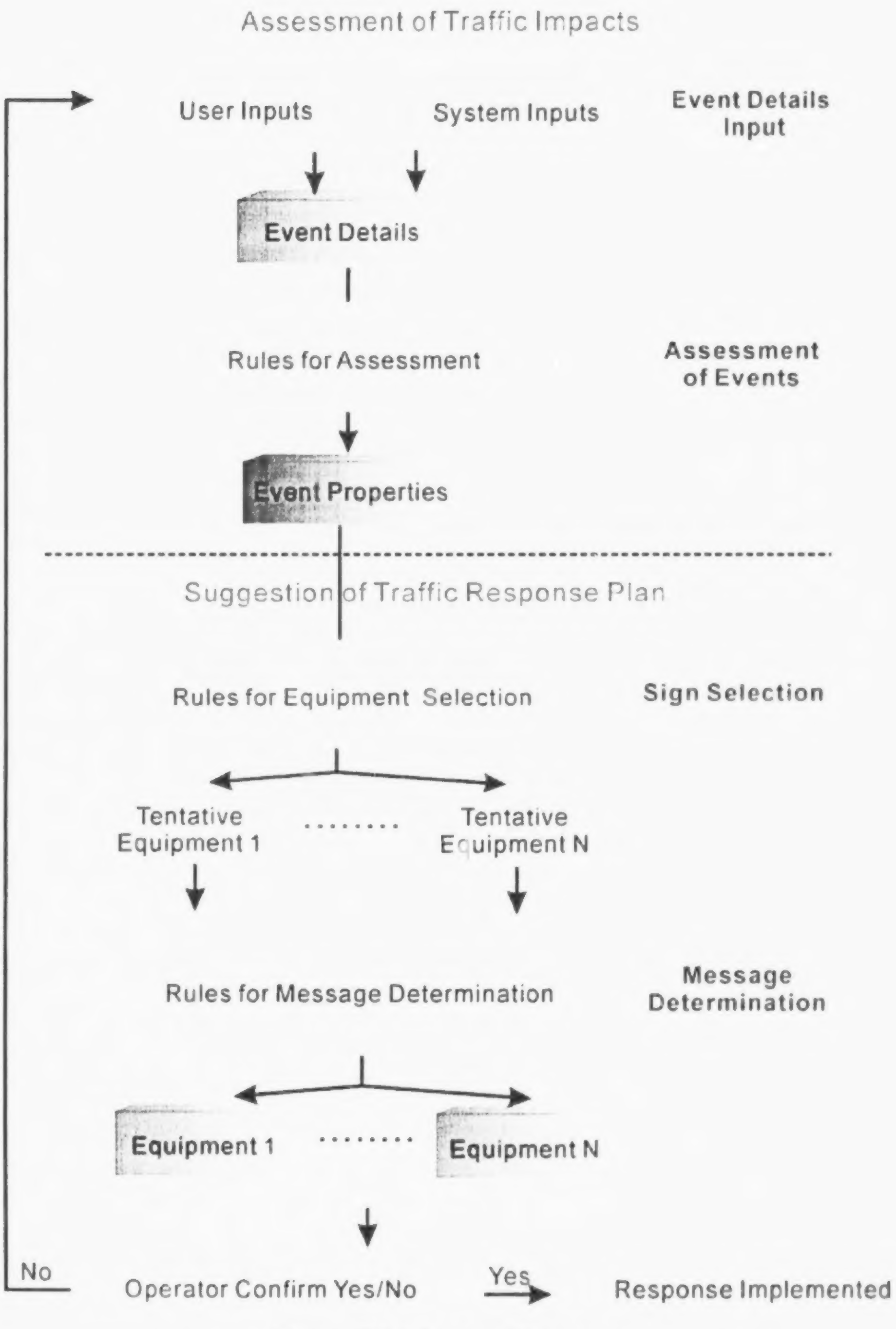
Assessment of Traffic Impacts
User Inputs
System Inputs
Event Details Input
Event Details
Rules for Assessment
Assessment of Events
Event Properties
Suggestion of Traffic Response Plan
Rules for Equipment Selection
Sign Selection
Tentative Equipment 1
....
Tentative Equipment N
Rules for Message Determination
Message Determination
Equipment 1
....
Equipment N
No
Operator Confirm Yes/No
Yes
Response Implemented

Figure B4.1 System Structure

The procedure flow among objects and processes is described in Figure B4.1.

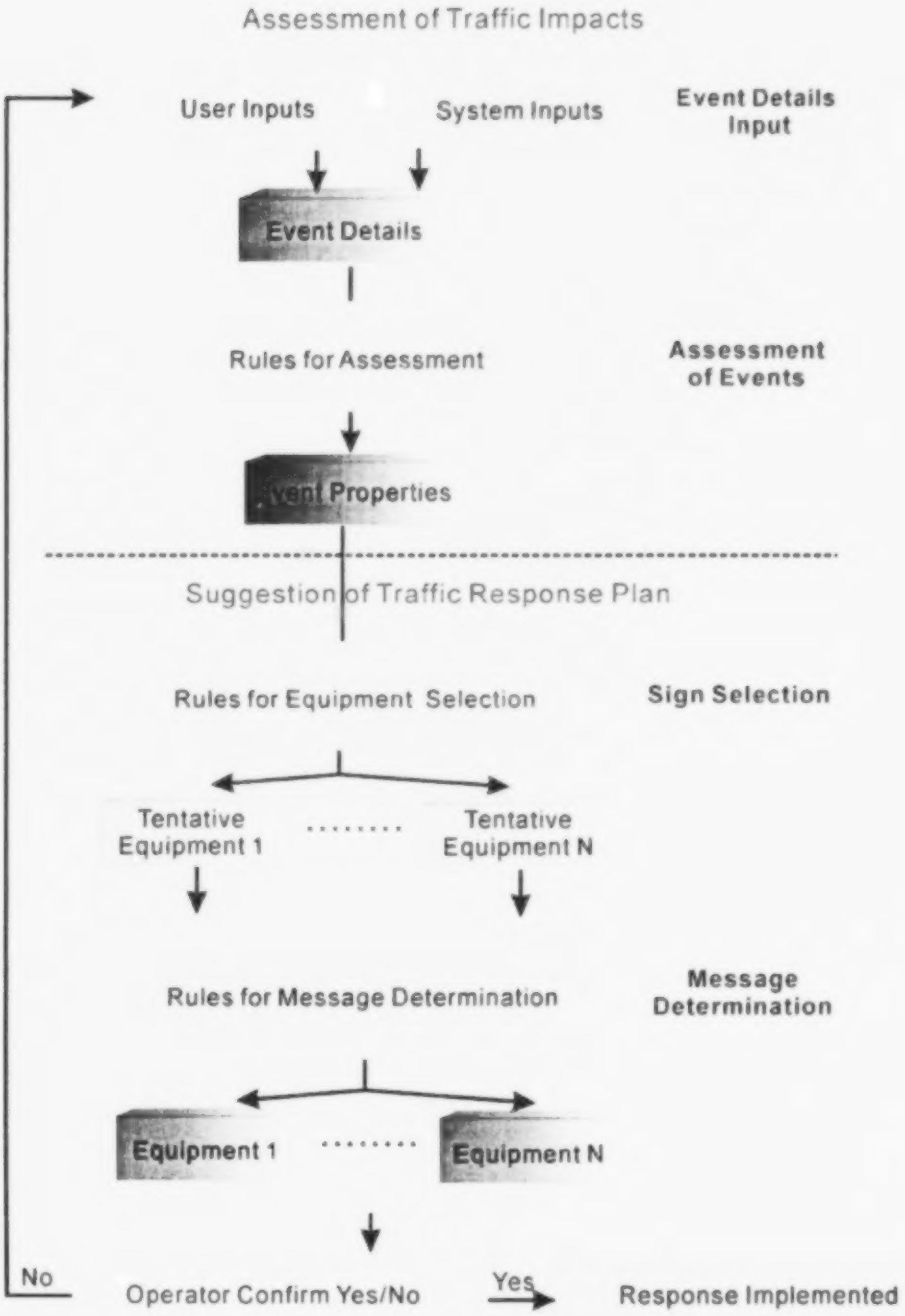
Assessment of Traffic Impacts
User Inputs
System Inputs
Event Details Input
Event Details
Rules for Assessment
Assessment of Events
Event Properties
Suggestion of Traffic Response Plan
Rules for Equipment Selection
Sign Selection
Tentative Equipment 1
Tentative Equipment N
Rules for Message Determination
Message Determination
Equipment 1
Equipment N
No
Operator Confirm Yes/No
Yes
Response Implemented

Figure B4.1 System Structure

5.0 System Component Analysis

After the system structure is defined, the operation of each process and the definition of each object are briefly explained in the following two sections. The detailed rules developed for the project are addressed in Section 6.

5.1 Processes

The four processes, namely event detail input, event assessment, sign selection and message determination, are discussed in the following sections.

5.1.1 Event Detail Input

The event detail input is a process that transforms the event details input by the user or by the system into an "event" object. The event detail input requires major factors such as event type, time, location and blockage pattern. Other factors such as number of vehicles, number of injuries and fatalities, and travel speed are also considered. These latter factors are useful when assistance from other agents and the estimated clearance time are needed. The details concerning event type, location and travel speed are further explained in section 6.

5.1.2 Event Assessment

The event assessment automates the process of selecting an appropriate traffic response plan. It assists operators and provides consistent responses to similar incidents. The function mainly takes the event details and generates event properties based on the following four considerations.

1. Event Categorization

Event assessment categorizes each event first. The following four control strategies are used:

- Lane-blocked incident type
- Congestion type
- Roadwork type
- Road condition type

2. Severity

Severity then is assessed for determining the signing extent. The severity is typically categorized into three levels: low, medium and high.

Different considerations are adopted for the first four types. For the lane-blocked incident and roadwork events, the factors to determine the severity level usually include clearance time, current traffic situation, type of roadway, and blockage pattern. The first two factors, the current traffic situation and the clearance time, are assessed according to the input incident details and pre-estimated index tables based on existing operations. Both factors are determined before determining the severity level. The latter factors, type of roadway and blockage pattern, are obtained from the input incident details. All four factors are considered together to determine the severity level. As for congestion events, the factor is the travel speed. For the road condition events, the factors include the rain accumulation or other measurable index.

3. Diversion

Diversion is assessed for determining a diversion strategy. The diversion strategies include total diversion, partial diversion and no diversion. This factor is used in selecting an appropriate CMS message template.

Different considerations are adopted for the first four event types. For the incident blocked or roadwork events, the factor considered is the blockage pattern. As for the congestion events, congestion severity levels are assessed in order to suggest a diversion strategy. It exams travel speeds from the parallel roads (i.e., express and collector lanes) within the same congestion control zone and determines a diversion strategy such as no diversion or partial diversion. As for the road condition events, no diversion strategy is suggested.

4. Event Combination

If an event occurs near a previous event (e.g. within 2 km), an event combination alarm is raised for operators to decide whether these two events shall be combined or not.

5.1.3 Sign Selection

The sign selection uses the event properties to determine the appropriate signing extent and then selects all the signs within the identified signing extent. The signing extent is determined based on event type, severity and type of roadway. An additional consideration is applied to handle the situation when the selected sign is unavailable. If the selected sign is not physically or mechanically available, the signing extent may be needed to be extended. When the system performs the sign selection, signs between the event location and the signing extent, as well as CMS signs located on connecting highways, are all selected to be displayed. Figure B5.1 illustrates an example how the rules work for sign selection.

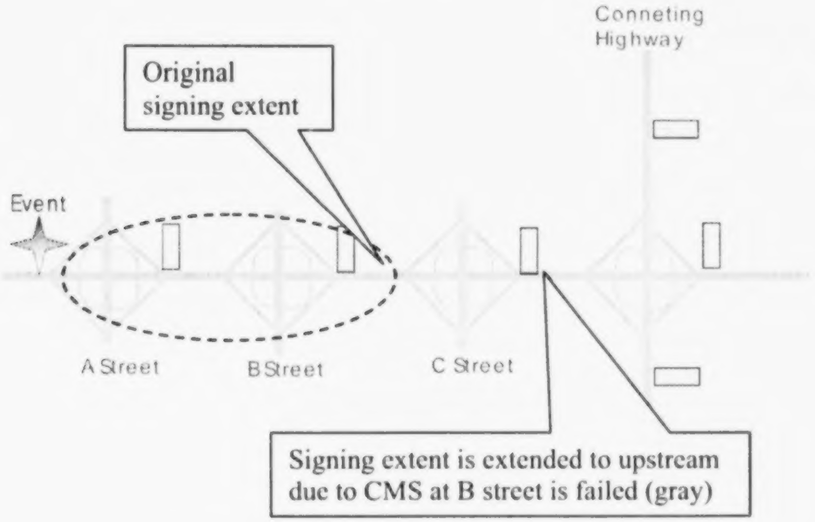
Conneting Highway
Original signing extent
Event
A Street
B Street
C Street
Signing extent is extended to upstream due to CMS at B street is failed (gray)

Figure B5.1 Example of Sign Selection

5.1.4 Message Determination

A set of rules is developed to select appropriate phrases from the FELG (Facility, Event, Location and Guidance) phrase library in response to the event. Factors that can determine the contents of displayed messages are event status, event type, CMS location relative to the event, event road type and CMS size. The event status represents different stage of an event such as event unconfirmed, event confirmed, event condition change (i.e. blockage pattern change or severity), or event cleared. When the event status has been changed, the message composition is reviewed. The event type and CMS location are the two key factors that determine the necessary phrases from the FELG message structure. The CMS size determines the need to use any abbreviations and the final message to be displayed.

When multiple events occur, several messages are proposed concurrently by the system. How to display such messages is an important issue to optimize CMS sign displays. Multiple phase messages, combining messages and message priority are used in resolving the issue. The design of applying multiple messages will follow the 9-second guideline in the human factor field. Multiple messages to be displayed sequentially must be readable and comprehendible by drivers within 9 seconds. This method is applied if the upstream travel speed is slow. Only two message phases are used in this method. When the speed is fast, the method of combining messages is applied. The considerations include the sign configuration and the distance between events. The priority method is last introduced when none of the above methods work. The priority determines the priority levels for multiple messages. The factor to be considered in the method mainly is based on event type.

5.2 Objects

From the above description of each process, the attributes of each object can be defined as follows:

The attributes of event details generally consist of the following items:

1. Location
2. Time
3. Event type
4. Details:
   - Blockage pattern
   - Number of vehicles
   - Number of injuries and fatalities
   - Travel speeds
   - Traffic data (e.g., traffic volume and occupancy)

The attributes of event properties generally consist of the following items:

1. Control strategies
2. Event Subtype
3. Time of day
4. Clearance time
5. Event road type
6. Event location
7. Blockage pattern
8. Traffic impact (e.g., high, medium and low)
9. Diversion strategy with the zone speeds

The attributes of tentative equipment generally consist of the following items:

1. Equipment ID
2. Equipment location
3. Proposed message
4. Distance to the event
5. Type of roadway where the sign located (e.g., mainline or connecting freeway, before transfer, etc.)
6. Immediate upstream travel speed
7. Travel time for the defined link
8. Sign configuration (e.g., numbers of lines and digits)

The attributes of equipment consist of the following items:

1. Equipment ID
2. Equipment location
3. Current message 1 (e.g., the message will be rotated with the current message 2)
4. Current message 2
5. Queue messages (four messages are awaited to be displayed when multiple messages are required)
6. Distance to the event
7. Type of roadway where the sign located (e.g., mainline or connecting freeway, before transfer, etc.)
8. Upstream travel speed

9. Travel time
10. Sign configuration (e.g., numbers of lines and digits)

6.0 Development of Response Plan Rules

This section addresses the event input requirements and all the rules developed for the three rule-based processes: event assessment, sign selection and message determination. A complete set of rules including all traffic response plans across regions is rather detailed and out of the project scope. The traffic response plan rules developed for this project will only focus on single roadway geometry, commonly used rules for typical traffic scenarios, and CMS graphic signs with 3 lines X 30 characters as examples.

6.1 Event Input Requirements

1. Event Type

The event types should be as specific as possible. The following list, containing some of recommended items based on ATMS operation as well as the roadway maintenance item, is adopted for this project:

Vehicle Fire (commercial vehicle)
Vehicle Fire (passenger car)
Overturned Truck
Traffic Collision
Hazardous Material
Spilled Load
Vehicle Fuel Spill
Hazardous Material Fire
Load Fire
Stalled Vehicle

Crime Investigation
Roadway Maintenance
Congestion
Snow Plowing
Fog/Dust/Smoke
Land Slide
Storm
Wind
Flood
Rain

2. Location

Location shall contain information like types of roadway, linear reference (i.e., milepost), blockage pattern and direction. The type of roadway is generally described as mainline, ramps, connecting freeway, express/collector, or arterial. It is one of the important factors required to determine the severity. The milepost is used to determine the distances between the event and CMS signs. The distance can be used in determining the display messages. If the event (e.g. car accident or planned roadwork) blocks lanes of roadway, the blockage pattern is required to determine the event severity and to be used for CMS message contents. The direction is used for CMS message contents.

In most highway systems around the world, the roadway type can generally be categorized into four groups:

- Mainline Road: sections on the highway.
- Ramp Roadway: Roadways that connect the urban street to the mainline of the highway at an interchange area

- Connecting Freeway: Freeways that connect to the highway at an interchange area.
- Arterial: Urban streets that run perpendicular to and connect with the highway at interchange areas.

Special roadway types of the mainline road type on Highway 401 are further defined since Highway 401 has the unique express/collector highway system. There are four types of roadway geometry defined in Highway 401 as follows:

- Single Road (S): Sections on Hwy. 401 that is prior to the split and after the merge of the express and collector system.
- Express Lanes (E): Inner stream of the express and collector system on Hwy. 401 with limited access to and from the collector lanes.
- Collector Lane (C): Outer stream of the express and collector system on Hwy. 401 with access to and from the connecting urban streets in the form of interchanges.
- Transfer Road (T): Roadways that connect the express and collector lanes.

However, rules for this project do not deal with these roadway types since this road geometry complicates the rules and may not apply to other regions.

3. Travel Speed

The travel speeds can be measured directly from vehicle detector stations. If vehicle detectors are installed, these levels can be inputted directly by the system. If not, then users have to define the approximate travel speed for this type of events.

6.2 Rules for Event Assessment

6.2.1 Event Categorization

Four control strategies are proposed to describe the nature of different traffic problems. The rules for identifying the control strategy in response to each event are defined in Table B6.1.

Table B6.1 Rules for identifying the event category

Event Type	Events
Lane-blocked incident type	Vehicle Fire (commercial vehicle) Vehicle Fire (passenger car) Overturned Truck Traffic Collision Hazardous Material Spilled Load Vehicle Fuel Spill Hazardous Material Fire Load Fire

Table B6.1 Rules for identifying the event category	
Event Type	**Events**
	Stalled Vehicle Crime Investigation
Congestion Type	Congestion
Roadwork Type	Roadway Maintenance (scheduled roadwork)
Road Condition Type	Snow Plowing Fog/Dust/Smoke Land Slide Storm Wind Flood Rain

6.2.2 Severity

Severity is an important index to describe the level of traffic impact caused by an incident. It is used in sign selection and message determination. Severity has three levels: high, medium and low.

Rule 1: Congestion type

Three severity levels are defined for congestion events: low, medium and high. The criteria for determining severity level are listed in Table B6.2.

Table B6.2 Rules for determining congestion severity level			
Severity Level	**High**	**Medium**	**Low**
Criteria	Under 40 km/h	Between 40 – 75 km/h	Above 75 km/h

Rule 2: Road condition type

The severity of snow plowing will be assigned high. The severity of other events under the category of road condition type will be assigned low.

Rule 3: Lane-blocked incident and roadwork types

The factors, clearance time; and time of day are estimated before the event assessment for the lane-blocked incident and roadwork types.

Rule 3.1: Clearance time

The clearance times for incident-type events are not defined for the COMPASS system. Therefore, this factor is not used for developing rule sets, but the design will keep this factor for a future enhancement. The following clearance times used for an ATMS operation are listed for reference:

Event Type	Event Clearance Time
Vehicle Fire (commercial vehicle)	2 hrs
Vehicle Fire (passenger car)	1 hr
Overturned Truck	4.5 hrs
Traffic Collision	0.5 – 1.5 hrs with injury; 3-5 hrs with fatality.
Hazardous Material	1 hr
Spilled Load	1 hr
Vehicle Fuel Spill	1 hr
Hazardous Material Fire	4 hrs
Load Fire	1 hr
Stalled Vehicle	0.5 hr
Crime Investigation	5 hrs

Rule 3.2: Current Traffic Situation

The current traffic situation is divided into three categories: heavy, medium, and light. The criteria for determining current traffic situation are defined in Table B6.3.

Table B6.3 Criteria for Determining Current Traffic Situation

	Heavy Traffic	Medium Traffic	Light Traffic
Criteria	The hourly volume for each lane exceeds 2000 vehicles and the average occupancy exceeds 25%	The hourly volume for each lane is between 2000 and 800 vehicles and the average occupancy is between 25% and 10%	The hourly volume for each lane is below 800 vehicles and the average occupancy is below 10%

Rule 3.3: Severity Assessment

For the events controlled by the incident management strategy and planned roadwork strategies, the severity is assessed based on factors like current traffic situation, blockage pattern and type of roadway. The rules for determining severity are explained in Figure B6.1.

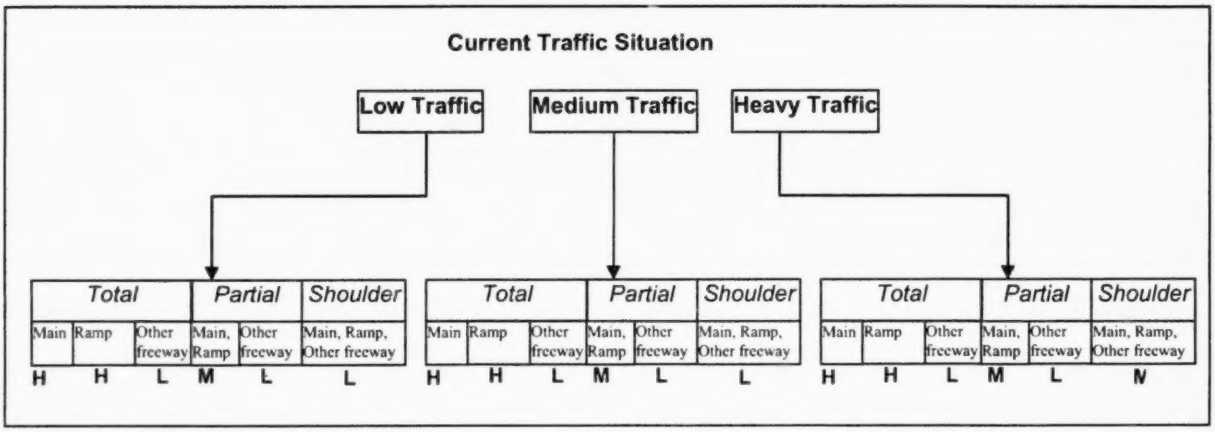
Current Traffic Situation
Low Traffic
Medium Traffic
Heavy Traffic
Total
Partial
Shoulder
Main
Ramp
Other freeway
Main, Ramp
Other freeway
Main, Ramp, Other freeway
H
H
L
M
L
L
Total
Partial
Shoulder
Main
Ramp
Other freeway
Main, Ramp
Other freeway
Main, Ramp, Other freeway
H
H
L
M
L
L
Total
Partial
Shoulder
Main
Ramp
Other freeway
Main, Ramp
Other freeway
Main, Ramp, Other freeway
H
H
L
M
L
M

Figure B6.1: Traffic Impact Determination Flowchart

6.2.3 Diversion

Rule 1: Lane-blocked incident and roadwork types

The diversion strategy has two levels: no diversion and total diversion. The factor for determining the diversion strategy for both event types depends on the blockage pattern. The rules are shown in Table B6.4.

Table B6.4 Rules for Determining Diversion Strategy

Diversion Strategy	Blockage Pattern
Total Diversion	Full closure or blockage
No Diversion	Partial closure or blockage

6.3 Rules for Sign Selection

6.3.1 Rules for Determining Signing Extent

Rule 1: Congestion type

The signing extent is the first CMS upstream of the congestion zone and any connecting roadway CMS that leads directly into the control zone.

Rule 2: Lane-blocked incident type

The determination of the signing extent for the lane-blocked incident type is based on the severity. The rules for three levels of severity are shown in Table B6.5.

Table B6.5 Signing Extent for Incident Management Strategy

	Signing Extent
Low	1st CMS upstream of incident upstream end location
Medium	1 upstream diversion point
High	2 upstream diversion points

Rule 3: Roadwork type

The determination of the signing extent for the scheduled roadwork type is based on the severity as well. The rules for determining the signing extent follow the same rules for the lane-locked incident type.

Rule 4: Road condition type

The determination of the signing extent for the road condition type (i.e. rain, fog, etc.) is also based on the severity. The rules for determining the signing extent follow the same rules for the lane-locked incident type.

6.3.2 Rules for Selecting Signs To Be Activated

Table B6.6 Rules for Selecting Signs To Be Activated

Rule#	Conditions	Actions
1	If {event status is not yet confirmed}	First upstream sign
2	If {event status is confirmed} & {CMS signs are located between the event and the signing extent} & {roadway type is E, S, C}	All CMS signs are selected to be displayed
3	If {event status is confirmed} & {CMS signs are located between the event and the signing extent} & {roadway type is T}	A CMS from each direction, which is upstream of the transferring road is selected.

6.3.3 Rules for Handling Sign Availability

Table B6.7 Rules for Handling Sign Availability

Rule#	Conditions	Actions
1	If {event status is confirmed} & {roadway type is E,C, S & T} & {event severity is high} & {no sign is located within the signing extent}	Use the next upstream sign within a distance (e.g., 15 km)
2	If {event status is confirmed} & {roadway type is E,C, S & T} & {event severity is high} & {the last sign within the signing extent fails}	Use the next upstream sign within a distance (e.g., 15 km)

6.4 Rules for Message Determination

The FELG phrase library and two sets of rules for composing messages and for handling multiple messages, respectively, are addressed. Details are described in the following sections.

6.4.1 FELG Phrase Library

In most Advanced Transportation Management Systems, the FELG structure is commonly used to determine a CMS message no matter whether system is built based on lookup tables, templates or rule-based. "FELG" represents "Facility", "Event", "Location" and "Guidance". Facility means road, bridge or tunnel. Any specific road section can give drivers a quick indication as to where the event is. Events contain any phrases that can describe the impact of the event effectively. The phrases for congestion events, weather events or other events that do not produce any roadway blockage can use the event name directly, such as "Congestion", "Rain", "Fog", etc. As for incidents or road maintenance works, the phrases commonly use the blockage pattern of the event, such as "All Lanes Blocked (/Closed)". Location can further describe the exact range of the event if the facility is a long section of roadway. Phrases used can be "Before", "Beyond", or "At". Guidance can provide suggestions that help drivers avoid the problem area or be aware of any hazard, such as " Use Next Exit", "Drive With Care", ...etc.

Some example phrases commonly used for Facility, Event, Location and Guidance are listed in Table B6.8.

Table B6.8 FELG Phrase Library

Category	Example Phrases	Message Code Number
Facility	**Hwy 401**	
	PEACE BRIDGE	
	{ramp name}	
	{1 st diversion point}	
Event Type	**ROAD CONGESTION**	
	RAIN/FOG/WIND/SNOW	
	{Blockage Pattern} **LANE{S} CLOSED**	
	{facility} **CLOSED**	
Location	**FROM** {Upstream end location}*	LFrm – From Location
	TO {Downstream end location}*	Lto- To Location
Guidance	**USE** {ramp name}	DS1- Diversion Suggestion
	TRAFFIC MUST EXIT AT {ramp name}	DS2- Diversion Suggestion
	PREPARE TO STOP	ES1- Emergency Stop
	DRIVE WITH CARE	CW1- Cautionary Warning
	KEEP YOUR DISTANCE	CW2- Cautionary Warning
	USE HEADLIGHTS	CW3- Cautionary Warning

Note1: {} means variable; bold words are fixed phrases.

Note2: Upstream and downstream end locations* use the following phrases:

Table B6.9 Definition of Location Phrases

Phrases	Definition
BEFORE {Ramp name}	between 0 and 500 meters before the off ramp of the interchange
AT {Ramp name}	between the off ramp and the on ramp of the interchange
BEYOND {Ramp name}	between the on ramp of the interchange to the point defined as the "BEFORE" point for the downstream interchange

6.4.2 Rules for Composing Messages

The message determination composes the messages for the selected signs according to the event type, event location, diversion strategy, and the location of the sign related to the incident. The rules are addressed as in Table B6.10.

Status Review

Table B6.10 Rules for Status Review

Rule#	Conditions	Actions
1	If {event status is not yet confirmed}	Message uses CW1
2	If {event status is confirmed}	Run message composition model
3	If {event status is condition change}	Run message composition model
4	If {event status is cleared}	Run message composition model

Message Composition

The rules for the message composition are developed based on the event type, CMS location relative to the event and CMS size.

Table B6.11 Rules for Message Composition		
Rule#	**Conditions**	**Actions**
1.1	If {event type is congestion} & {the CMS sign is located upstream of the congestion}	Line 1: {Facility} {Event Type} Line 2: LFrm Line 3: LTo
1.2	If {event type is congestion} & {the CMS sign is caught in congestion}	Line 1: {Facility} {Event Type} Line 2: LTo
2.1	If {event type is incident or planned road work} & {road geometry is mainline} & {blockage pattern is partial} & {the CMS sign is located at upstream of maximum safe stop distance}	Line 1: {Facility}{blockage pattern} **LANE{S} CLOSED** Line 2: LFrm Line 3: LTo
2.2	If {event type is incident or planned road work} & {road geometry is mainline} & {blockage pattern is partial} & {the CMS sign is located within upstream of maximum safe stop distance}	Line 1: ESW1
2.3	If {event type is incident or planned road work} & {road geometry is mainline} & {blockage pattern is total blocked} & {the CMS sign is located at upstream of 2nd diversion point}	Line 1&2: {facility} **CLOSED** & LFrm & LTo Line 3: guidance phrase DS1
2.4	If {event type is incident or planned road work} & {road geometry is mainline} & {blockage pattern is total blocked} & {the CMS sign is located between 2nd diversion point and 1st diversion point}	Line 1&2: {facility} **CLOSED** & LFrm & LTo Line 3: guidance phrase DS2
2.5	If {event type is incident or planned road work} & {road geometry is mainline} & {blockage pattern is total blocked} & {the CMS sign is located between 1st diversion point and the event}	Line 1&2: {facility} **CLOSED AHEAD** Line 3: guidance phrase CW1
2.6	If {event type is incident or planned road work} & {road geometry is mainline} & {blockage pattern is total blocked} & {the CMS sign is located before the diversion points on connecting highway}	Line 1&2: {facility} **CLOSED** & LFrm & LTo Line 3: guidance phrase DS1

Table B6.11 Rules for Message Composition		
Rule#	**Conditions**	**Actions**
2.7	If {event type is incident or planned road work} & {road geometry is ramp} & {blockage pattern is total blocked}	Line 1: {Ramp Name} Line 2: **CLOSED**
3.1	If {event type is road condition} & {event sub-type is rain/fog/storm}	Line 1: {Rain/Fog/Storm} Line 2: LFrm & LTo Line 3: CW3
3.2	If {event type is road condition} & {event sub-type is rain/fog/storm}	Line 1: {Rain/Fog/Storm} Line 2: CW1
3.3	If {event type is road condition} & {event sub-type is snow plowing}	Line 1: {event} Line 2: **IN** {event road type} Line 3: CW1

6.4.3 Rules for Handing Multiple Messages

After the messages are composed, the message text is stored in the field for proposed messages in the tentative equipment object. The message in the tentative equipment is not implemented immediately. The process checks the content and the priority of the current message in the object of "equipment".

Table B6.12 Rules for Handing Multiple Messages		
Rule#	**Conditions**	**Actions**
1.1	If {current message 1 is empty}	Place the proposed message on the current message 1 and display the proposed message
2.1	If {current message 1 is not empty} & If {travel speed upstream of the sign is below a threshold speed (e.g. 20 km/h)}	The proposed message is placed in the current message 2. Both current messages are rotated sequentially
2.2	If {current message 1 is not empty} & {the travel speed of the sign is above the threshold speed (e.g., 20 km/h)} & {the sign is 3 lines X 30 digits} & {the event combination is incident and congestion; roadwork and congestion; or incident and Weather}	Follow the rules in Table 6.13.
2.3	If {current message 1 is not empty} & {the travel speed of the sign is above the threshold speed (e.g., 20 km/h)} &	Prioritize messages (i.e. priority from high to low as incident, snow-

Table B6.12 Rules for Handing Multiple Messages

Rule#	Conditions	Actions
	{the sign is 3 lines X 30 digits} & {event combination is not considered} {Both events are not the same event type}	plowing, congestion, roadwork)
2.4	If {current message 1 is not empty} & {the travel speed of the sign is above the threshold speed (e.g., 20 km/h)} & {the sign is 3 lines X 30 digits} & {event combination is not considered} {Both events are the same event type} {Distance between two event is greater than a distance threshold (i.e. 1 km)}	The event which is closer to the sign location has higher priority
2.5	If {current message 1 is not empty} & {the travel speed of the sign is above the threshold speed (e.g., 20 km/h)} & {the sign is 3 lines X 30 digits} & {event combination is not considered} {Both events are the same event type} {Distance between two event is less than a distance threshold (i.e. 1 km)}	The event whose severity is higher has higher priority
2.6	If {current message 1 is not empty} & {the travel speed of the sign is above the threshold speed (e.g., 20 km/h)} & {the sign is 3 lines X 12 digits (or 3 X 8) }	Prioritize messages (i.e. priority from high to low as incident, snow-plowing, congestion, roadwork)

Table B6.13 Three Message Templates for Combining Messages

Event 1	Event 2	Message Content
Incident	Congestion	Line 1: **SLOW TO** queue end location} Line 2: {blockage pattern} **LANE{S} CLOSED**
Roadwork	Congestion	Line 1: **SLOW TO** {queue end location} Line 2: {blockage pattern} **LANE{S} CLOSED**
Incident	Weather	Line 1: {Rain/Fog/Wind/Snow} Line 2: {blockage pattern} **LANE{S} CLOSED** Line 3: From {Upstream end location}

7.0 Additional Functional Requirements

Additional functional requirements to be addressed in the system design are as follows:

1. Capability of Manually Modifying a System-recommended Plan

The system will have a plan verification screen to allow operators to change the suggested traffic response plan detail. Before the traffic response plan is implemented, this screen will be displayed for the operator to verify the traffic response plan. It will also allow the operator to change display messages or add/cancel a CMS.

2. Capability of Modifying Rules

The system will have a rule edit screen to allow operators to modify the rule database. The screen will have three functions:

- All attributes are listed for the users to select as the inputs as well as the outputs.
- Plans can be named by the users.
- The relationships among the inputs such as "and" & "or " and "If.....Then" can be specified by the users.

3. Capability of Modifying Equipment Navigation Configurations

The system will have an equipment navigation configuration edit screen to allow operators to modify the equipment navigation configuration, add a new sign or delete a sign. This function stores all needed geographic and physical information for the network of interest. The equipment configuration shall contain the following items:

- Sign number
- Link number
- Link distance
- Number of lanes for the link
- Sign distance to the start point of the link (upstream point)
- Sign configuration (number of lines and words)
- Roadway type where the sign is located
- Diversion point (yes or no)
- Upstream link 1
- Upstream link 2
- Upstream link 3
- Upstream connecting highway link 1
- Upstream connecting highway link 2
- Congestion zone 1
- Congestion zone 2
- Zone 1 speed
- Zone 2 speed
- Upstream travel speed

APPENDIX C

Evaluation Report on New CMS Message Generation Techniques

TABLE OF CONTENTS

Page

1. PURPOSE 1

2. METHODOLOGY 1

2.1 Evaluation Environment 1

2.2 Evaluation Scenarios 4

3. EVALUATION CRITERIA 4

4. EVALUATION 5

4.1 Evaluation Process 5

4.2 Evaluation Details 6

4.3 Summary 28

5. CONCLUSIONS AND RECOMMENDATIONS 29

5.1 Conclusions 29

5.2 Recommendations 29

LIST OF FIGURES

Figure C1.1 Evaluation Environment

Figure C1.2 Schematic Diagram of the Evaluation Environment

ACRONYMS

ATMS	Advanced Traffic Management System
CMS	Changeable Message Sign
ISMS	Intelligent Sign Management System
MTO	Ministry of Transportation of Ontario
NB	Northbound
SB	Southbound
VMS	Variable Message Sign (alternative to CMS)
WB	Westbound

1. Purpose

The purpose of this evaluation is to validate the Intelligent Sign Management System (ISMS) concept. The evaluation shall demonstrate that the ISMS can produce valid responses for freeway traffic management scenarios and prove the ISMS prototype is a useful tool to manage traffic responses efficiently.

2. Methodology

The evaluation used the MTO COMPASS system outputs for the validation. Both outputs from the ISMS and COMPASS were examined under several scenarios in an off-line environment. An area with connecting freeways and express/collector along Highway 401 was selected as the evaluation environment. The details of the selected area are described in Section 2.1. Several representative scenarios were prepared based on this area. The evaluation scenarios were simulated events rather than the real historical events, due to the complexity of retrieving traffic responses for real events from COMPASS. The scenarios covered the initiation of an event; the event update and event termination were not included. Evaluating how the system responded to event initiation is sufficient to prove the concept of the ISMS. The details of the scenarios are described in Section 2.2.

2.1 Evaluation Environment

The sample area for the system evaluation was a section of Highway 401 between Victoria Park Avenue and Highway 400. This section of highway network is a good example because of the complex roadway geometry. This section contains express and collectors running parallel with two connecting highways (i.e., Highway 404 and Allen Road) and eight crossroads. A total of 16 Changeable Message Signs are installed in this section. The sample area is illustrated in Figure C1.1.

We selected to demonstrate all scenarios in the westbound section of Highway 401 (see Figure C1.2). This diagram identifies the nodes – where traffic merges or diverges – and links, which are the segments of highway and ramps. The nodes are named according to their geometry (i.e. C#: collector; E#: express and R#: ramp). The links are differentiated into three categories: black-solid (highway), black-dash (transfer), and gray-solid (ramp). The existing CMS signs are shown in an orange square. The CMS signs in this project are 3-line signs, with 30 characters per line.

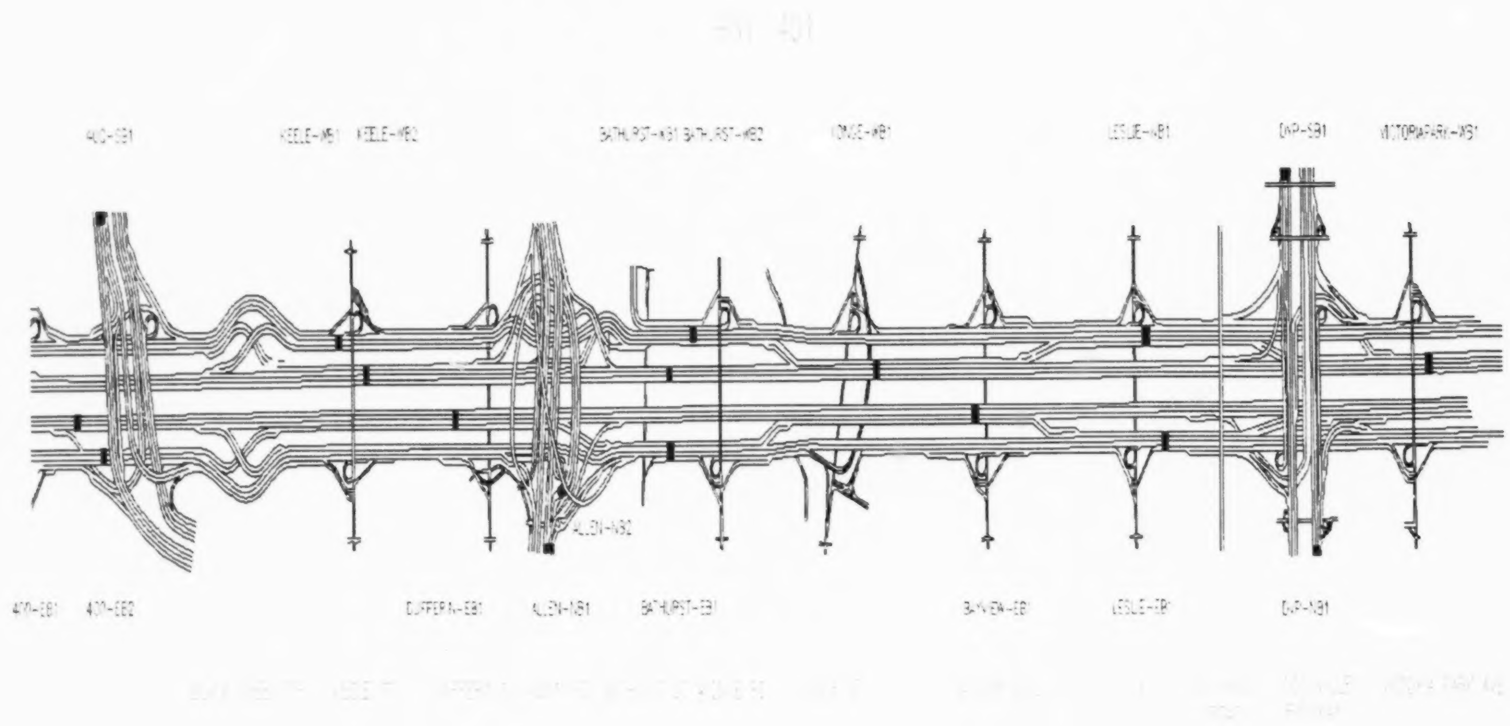
HWY 401
400-SB1
KEELE-WB1
KEELE-WB2
BATHURST-WB1
BATHURST-WB2
YONGE-WB1
LESLIE-WB1
DVP-SB1
VICTORIAPARK-WB1
ALLEN-NB2
400-EB1
400-EB2
DUFFERIN-EB1
ALLEN-NB1
BATHURST-EB1
BAYVIEW-EB1
LESLIE-EB1
DVP-NB1

Figure C1.1 Evaluation Environment

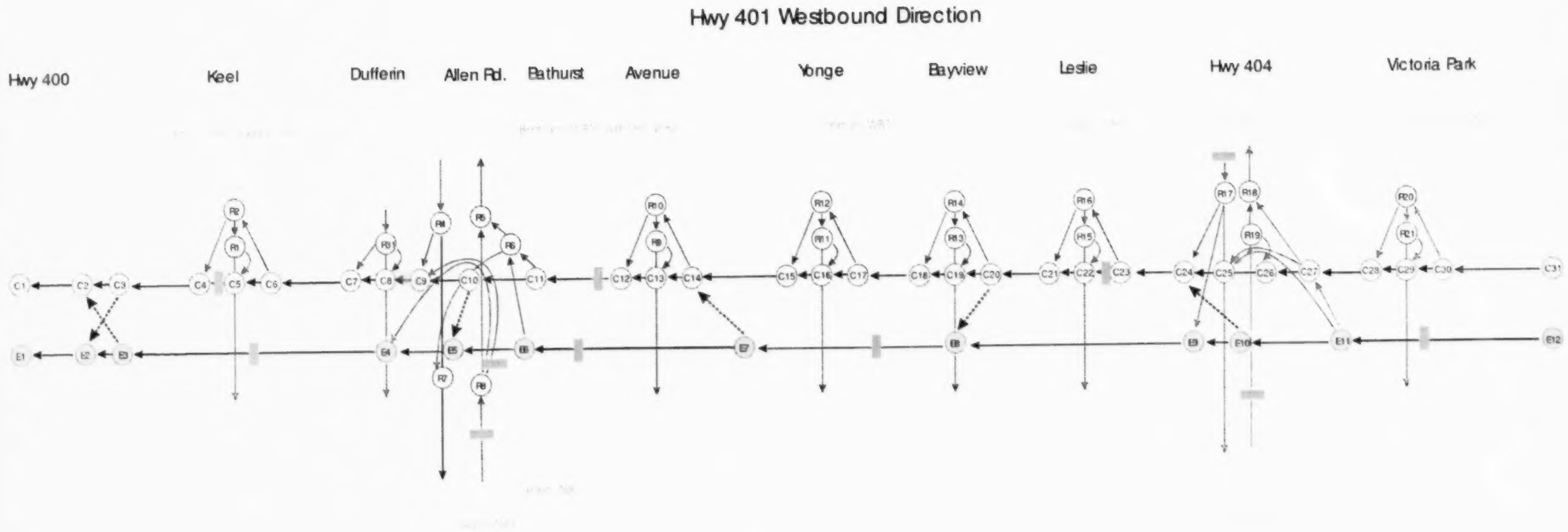
Hwy 401 Westbound Direction
Hwy 400
Keel
Dufferin
Allen Rd.
Bathurst
Avenue
Yonge
Bayview
Leslie
Hwy 404
Victoria Park
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
C19
C20
C21
C22
C23
C24
C25
C26
C27
C28
C29
C30
C31
E1
E2
E3
E4
E5
E6
E7
E8
E9
E10
E11
E12
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21

Figure C1.2 Schematic Diagram of the Evaluation Environment

2.2 Evaluation Scenarios

The ISMS prototype was developed based on the functions and rules described in Appendix B "Technical Report on New CMS Message Generation Techniques". Thirteen scenarios were prepared to evaluate the ISMS responses in comparison to the outputs from the existing MTO COMPASS. The scenarios were as follows:

1. Shoulder Blockage Incident
2. Partial Blockage Incident
3. Collector Total Blockage Incident
4. Collector & Express Total Blockage Incident
5. Express Congestion
6. Collector Total Blockage Roadwork
7. Severe Rain
8. Event Combination 1 (Stalled Vehicle and Traffic Collision)
9. Event Combination 2 (Previous Condition and Traffic Congestion)
10. Display Multiple Messages
11. Multiple Stages of an Event
12. Add a New Sign
13. Change Rules

Scenarios 1 to 7 evaluate the ISMS responses to single events such as incident, roadwork, congestion and weathers; Scenarios 8 to 10 demonstrate multiple events. Scenario 11 demonstrates handling multiple stages of an event, and Scenarios 12 and 13 evaluate the flexibility of the ISMS prototype when a system expanded or the traffic practice changed.

The content of each scenario includes the purpose, the existing traffic condition prior to the event, event details, ISMS outputs, COMPASS outputs, evaluation comments and actions.

3. Evaluation Criteria

The evaluation compares the outputs generated by the ISMS to COMPASS. The outputs from each system include the activated signs and their displayed messages. It should be noted that matching both outputs word by word is not the purpose because both systems use different design concepts. COMPASS was developed based on the table-lookup approach with extensive local traffic response considerations in Ontario. The ISMS is a prototype system that adopts a rule-based approach for advancing the freeway management technology to meet various event management requirements of many regions. Thus, the outputs from both systems will be similar but not identical. The criteria used for comparison are:

1. The number of activated CMS signs

   The number of activated CMS signs and the locations of the activated signs shall be the same.

2. Similarity of message contents

The message contents shall be similar; that is, they shall use the same message pattern. The message pattern used in many regions includes three items:

a. Problem (i.e., event)
b. Location
c. Advisory (optional)

The details in each item are subject to local practices. If the generated message addresses both the problem and the event location, then they are similar.

If the outputs from both systems did not match, a further evaluation of the traffic control strategies and multiple messages handling rules was conducted. After the corrective actions were implemented, the scenario was run again.

In addition to the comparing the outputs from both systems, the rule development tool was also evaluated independently to determine the ease of changing rules or adding rules.

4. Evaluation

4.1 Evaluation Process

The evaluation scenarios were sent to MTO to gather the COMPASS outputs. MTO requested that the traffic condition be included in each scenario. The traffic condition (i.e., congestion area and the level of congestion, such as moving, slowing and moving very slow) was determined and added for each scenario. The outputs from COMPASS were then collected. COMPASS does not have some features that were built in ISMS, such as multiple message handling, weather events, or rule changes; therefore, comparisons could not be done for Scenarios 7 to 10, and 12 and 13.

The evaluation was conducted twice. In the first evaluation, Scenarios 2, 3, 5 and 6 did not match. Our analysis of the results concluded that the traffic congestion should be included as secondary event in order to produce similar results. For Scenarios 2, 3 and 6, the traffic control strategy in the ISMS prototype required modifications. For Scenario 5 (congestion), the two systems used different traffic control strategies and the results were different. After these corrective actions were implemented, the second evaluation was conducted successfully.

4.2 Evaluation Details

The details of both evaluations are documented in the following 13 tables.

EVALUATION NO.	**1**	
SCENARIO	**Shoulder Blockage Incident**	
Purpose	Demonstrate capability to select CMS signs and compose messages in response to a shoulder blockage incident.	
Existing Condition Prior to the Test Event	Time of day: 11:00 AM Current traffic condition: Moving well CMS display: Default messages	
Event Inputs	Event: Traffic collision Location: Collector, downstream of interchange Dufferin St. (link from node C7 to node C6) Blockage pattern: Right shoulder Severity: Low Traffic condition: Moving well on all links	
ISMS FINAL OUTPUTS		
CMS Location	Sign Name	Message
1st Upstream	Bathurst_WB2	"Collector Right Shoulder Blocked Beyond Allen"
COMPASS OUTPUTS		
WB coll at basketweave	401VE0010VWC **Keel_WB1**	Scheduled safety message
WB exp at basketweave	401VE0010VWE **Keel_WB2**	Scheduled safety message
NB Allen to WB 401 ramp	401VE0020VWR **Alan_NB2**	Scheduled safety message
NB Allen to 401 ramps	401VE0010VNA **Alan_NB1**	Scheduled safety message
WB coll west of Avenue Road	401VE0020VWC **Bathurst_WB2**	^EARLIER INCIDENT ^MOVED TO SHOULDER ^BEYOND ALLEN
WB exp near Yonge	401VE0030VWE **Yonge_WB1**	Default guide signing message
WB coll near Leslie	401VE0030VWC **Leslie_WB1**	Default guide signing message
SB 404 at VanHorne	401VE0060VSF **DVP_SB1**	Scheduled safety message
NB DVP at Three Valley	401VE0070VNF **DVP_NB1**	Scheduled safety message
WB 401 near Victoria Park	401VE0040VWE **VictoriaPark_WB1**	Scheduled safety message
EVALUATION COMMENT AND ACTION		
MTO comment - depending on the traffic flow conditions around the shoulder incident location, the operator may or may not dispatch the above system-recommended response plan.		

EVALUATION NO.	**2**	
SCENARIO	**Partial Blockage Incident**	
Purpose	Demonstrate capability to select CMS signs and compose messages in response to a partial blockage incident.	
Existing Condition Prior to the Test Event	Time of day: 10:00 AM Current traffic condition: Moving well CMS display: Default messages	
Event Inputs	Event: Traffic collision Location: Collector, downstream of interchange Dufferin St. (link from node C7 to node C6) Blockage pattern: 1 right lane Severity: Medium-low Traffic condition: Moving slowly on collector links between C11 and C7.	
ISMS FINAL OUTPUTS		
CMS Location	Sign Name	Message
1st Upstream	Bathurst_WB2	"Collector 1 Right Lane Blocked Beyond Allen Congested To Beyond Allen"
Connecting Roadway	Allen_NB2	"401 Collector 1 Right Lane Blocked Beyond Allen Congested To Beyond Allen"
Connecting Roadway Congestion	Yonge_WB1	"Collector 1 Right Lane Blocked Beyond Allen Congested To Beyond Allen"
COMPASS OUTPUTS		
WB coll at basketweave	401VE0010VWC **Keel_WB1**	Scheduled safety message
WB exp at basketweave	401VE0010VWE **Keel_WB2**	Scheduled safety message
NB Allen to WB 401 ramp	401VE0020VWR **Alan_NB2**	+ 1 RGHT LANE BLOCKED (401) IN COLLECTOR WEST BEYOND ALLEN
NB Allen to 401 ramps	401VE0010VNA **Alan_NB1**	Scheduled safety message
WB coll west of Avenue Road	401VE0020VWC **Bathurst_WB2**	^1 RIGHT LANE BLOCKED ^IN COLLECTOR ^BEYOND ALLEN
WB exp near Yonge	401VE0030VWE **Yonge_WB1**	^EXRPESS MOVING WELL ^COLLECTOR MOVING SLOWLY ^BEYOND NEXT TRANSFER
WB coll near Leslie	401VE0030VWC **Leslie_WB1**	Default guide signing message
SB 404 at VanHorne	401VE0060VSF **DVP_SB1**	Scheduled safety message

NB DVP at Three Valley	401VE0070VNF **DVP_NB1**	Scheduled safety message
WB 401 near Victoria Park	401VE0040VWE **VictoriaPark_WB1**	Scheduled safety message

EVALUATION COMMENT AND ACTION

1st Evaluation

The ISMS outputs were as follows:

Bathurst_WB2	"Collector Right 1 Lane Blocked Beyond Dufferin St"
Bathurst_WB1	"Collector Right 1 Lane Blocked Beyond Dufferin St"

The outputs did not match with COMPASS. After the evaluation, a secondary event, traffic congestion, needed to be included in the scenario in order to produce similar results.

2nd Evaluation

The activated signs from ISMS and COMPASS are the same.

The generated messages from the ISMS prototype address more information, including the lane-blocked incident and congestion messages. The two messages were combined together for the evaluation. This feature demonstrated the ISMS prototype could provide more information for all the signs.

EVALUATION NO.	**3**
SCENARIO	**Collector Total Blockage Incident**
Purpose	Demonstrate capability to select CMS signs and compose messages in response to a collector total blockage incident.
Existing Condition Prior to the Test Event	Time of day: 14:00 PM Current traffic condition: Moving well CMS display: Default messages
Event Inputs	Event: Traffic collision Location: Collector, downstream of Interchange Dufferin St. (link from node C7 to node C6) Blockage pattern: All lanes Severity: Medium-high Traffic condition: Moving very slow on links between C15 and C7.

ISMS FINAL OUTPUTS

CMS Location	Sign Name	Message
1st Upstream	Bathurst_WB2	1st Message : "Collector All Lanes Blocked Beyond Allen Traffic Must Exit At Allen" 2nd Message: "Collector Congested To Beyond Allen"
2nd Upsream	Leslie_WB1	1st Message: "Collector All Lanes Blocked Beyond Allen Thru Traffic Use Express" 2nd Message: "Collector Congested From Beyond Avenue Rd. To Beyond Allen"
3rd Upsream	VictoriaPark_WB1	"Collector All Lanes Blocked Beyond Allen Thru Traffic Use Express"
Connecting Roadway	Yonge_WB1	1st Message: "Collector All Lanes Blocked Beyond Allen Thru Traffic Use Express" 2nd Message: "Collector Congested From Beyond Avenue Rd. To Beyond Allen"
	Allen_NB2	1st Message: "401 Collector All Lanes Blocked Beyond Allen" 2nd Message; "Collector Congested From Beyond Avenue Rd. To Beyond Allen"
	DVP_SB1	"401 Collector All Lanes Blocked Beyond Allen"
	DVP_NB1	"401 Collector All Lanes Blocked Beyond Allen"

COMPASS OUTPUTS

WB coll at basketweave	401VE0010VWC **Keel_WB1**	Scheduled safety message
WB exp at basketweave	401VE0010VWE **Keel_WB2**	Scheduled safety message

NB Allen to WB 401 ramp	401VE0020VWR **Alan_NB2**	+ COLLECTOR LANES (401) BLOCKED WEST BEYOND ALLEN
NB Allen to 401 ramps	401VE0010VNA **Alan_NB1**	Scheduled safety message
WB coll west of Avenue Road	401VE0020VWC **Bathurst_WB2**	^COLLECTOR LANES BLOCKED ^BEYOND ALLEN ^THRU TRAFFIC USE EXPRESS
WB exp near Yonge	401VE0030VWE **Yonge_WB1**	^COLLECTOR LANES BLOCKED ^BEYOND ALLEN ^THRU TRAFFIC USE EXPRESS
WB coll near Leslie	401VE0030VWC **Leslie_WB1**	^COLLECTOR LANES BLOCKED ^BEYOND ALLEN
SB 404 at VanHorne	401VE0060VSF **DVP_SB1**	+ COLLECTOR LANES (401) BLOCKED WEST BEYOND ALLEN
NB DVP at Three Valley	401VE0070VNF **DVP_NB1**	+ COLLECTOR LANES (401) BLOCKED WEST BEYOND ALLEN
WB 401 near Victoria Park	401VE0040VWE **VictoriaPark_WB1**	^COLLECTOR LANES BLOCKED ^BEYOND ALLEN

EVALUATION COMMENT AND ACTION

1st Evaluation

The ISMS outputs were as follows:

Bathurst_WB2	"Collector All Lanes Blocked Beyond Dufferin St Traffic Must Exit At Allen Rd."
Leslie_WB1	"Collector All Lanes Blocked Beyond Dufferin St Use Allen Rd"
Yonge_WB1	"Collector All Lanes Blocked Beyond Dufferin St"
Allen_NB2	"401 Collector All Lanes Blocked Beyond Dufferin St"

The activated signs from ISMS and COMPASS were different.

The rule in the ISMS prototype handled only 2 upstream diversion points and 1 upstream sign on all connecting roadways. The sign selection rule set in ISMS under this scenario needed to be adjusted to 3 upstream diversion points. The messages are similar.

2nd Evaluation

The activated signs from ISMS and COMPASS are the same. The messages are similar.

The congestion message was displayed as the 2nd message. The message combination could not be used in this scenario due to the restriction of the sign size. The rule uses a multiple-message strategy to show both messages on the same sign instead of message combination.

EVALUATION NO.	**4**	
SCENARIO	**Collector and Express Total Blockage Incident**	
Purpose	Demonstrate capability to select CMS signs and compose messages in response to a collector and express total blockage incident.	
Existing Condition Prior to the Test Event	Time of day: 23:00 PM Current traffic condition: Moving well CMS display: Default messages	
Event Inputs	Event: Traffic collision Location: Express & Collector, downstream of interchange Dufferin St. (link from node C7 to node C6 & link from node E4 to node E3) Blockage pattern: Total roadway blockage Severity: High Traffic condition: Moving slowly on links between C11 and C7 and links between E5 and E4	
ISMS FINAL OUTPUTS		
CMS Location	Sign Name	Message
1st Upstream	Bathurst_WB2	1st Message : "Express and Collector Blocked Beyond Allen Traffic Must Exit At Allen" 2nd Message : "Express and Collector Congested From Beyond Bathurst Rd. To Beyond Allen"
	Bathurst_WB1	1st Message : "Express and Collector Blocked Beyond Allen Traffic Must Exit At Allen" 2nd Message : "Express and Collector Congested From Beyond Bathurst Rd. To Beyond Allen"
2nd Upsream	Leslie_WB1	"Express and Collector Blocked Beyond Allen Use Allen"
	Yonge_WB1	"Express and Collector Blocked Beyond Allen Use Allen"
3rd Upstream	VictoriaPark_WB1	"Express and Collector Blocked Beyond Allen"
Connecting Roadway	Allen_NB2	1st Message : "401 Express and Collector Blocked Beyond Allen" 2nd Message ; "Express and Collector Congested From Beyond Bathurst Rd. To Beyond Allen"
	DVP_NB1	"401 Express and Collector Blocked Beyond Allen"
	DVP_SB1	"401 Express and Collector Blocked Beyond Allen"
COMPASS OUTPUTS		
WB coll at basketweave	401VE0010VWC **Keel_WB1**	Scheduled safety message
WB exp at basketweave	401VE0010VWE **Keel_WB2**	Scheduled safety message

NB Allen to WB 401 ramp	401VE0020VWR **Alan_NB2**	+ ALL LANES BLOCKED (401) BEYOND ALLEN WEST
NB Allen to 401 ramps	401VE0010VNA **Alan_NB1**	Scheduled safety message
WB coll west of Avenue Road	401VE0020VWC **Bathurst_WB2**	^EXPRESS AND COLLECTOR ^ALL LANES BLOCKED ^BEYOND ALLEN
WB exp near Yonge	401VE0030VWE **Yonge_WB1**	^EXPRESS AND COLLECTOR ^ALL LANES BLOCKED ^BEYOND ALLEN
WB coll near Leslie	401VE0030VWC **Leslie_WB1**	^EXPRESS AND COLLECTOR ^ALL LANES BLOCKED ^BEYOND ALLEN
SB 404 at VanHorne	401VE0060VSF **DVP_SB1**	+ ALL LANES BLOCKED (401) BEYOND ALLEN WEST
NB DVP at Three Valley	401VE0070VNF **DVP_NB1**	+ ALL LANES BLOCKED (401) BEYOND ALLEN WEST
WB 401 near Victoria Park	401VE0040VWE **VictoriaPark_WB1**	^EXPRESS AND COLLECTOR ^ALL LANES BLOCKED ^BEYOND ALLEN

EVALUATION COMMENT AND ACTION

1st Evaluation

The activated signs from ISMS and COMPASS were the same. The messages were similar.

2nd Evaluation

A congestion event was included and the congestion message was displayed as the 2nd message. The message combination could not be used in this scenario due to the restriction of the sign size. The rule uses a multiple-message strategy to show both messages on the same sign instead of message combination.

EVALUATION NO.	**5**	
SCENARIO	**Express Congestion**	
Purpose	Demonstrate capability to select CMS signs and compose messages in response to heavy congestion.	
Existing Condition Prior to the Test Event	Time of day: 19:00 PM Current traffic condition: Moving well CMS display: Default messages	
Event Inputs	Event: Congestion Location: Express, between interchange Dufferin St. and downstream of interchange Avenue Rd. (All links between node E7 and node E4) Blockage pattern: N/A Severity: High Traffic condition: Moving slowly on links between E7 and E4	
ISMS FINAL OUTPUTS		
CMS Location	Sign Name	Message
Caught in Queue	Bathurst_WB2	"Express Congested To Beyond Allen"
1st Upstream	Yonget_WB1	"Express Congested From Beyond Avenue Rd. To Beyond Allen"
Connecting Roadway	Lesile_WB1	"Express Congested From Beyond Avenue Rd. To Beyond Allen"
COMPASS OUTPUTS		
WB coll at basketweave	401VE0010VWC **Keel_WB1**	Scheduled safety message
WB exp at basketweave	401VE0010VWE **Keel_WB2**	Scheduled safety message
NB Allen to WB 401 ramp	401VE0020VWR **Alan_NB2**	Scheduled safety message
NB Allen to 401 ramps	401VE0010VNA **Alan_NB1**	Scheduled safety message
WB coll west of Avenue Road	401VE0020VWC **Bathurst_WB2**	Scheduled safety message
WB exp near Yonge	401VE0030VWE **Yonge_WB1**	^EXPRESS MOVING SLOWLY ^COLLECTOR MOVING WELL ^BEYOND NEXT TRANSFER
WB coll near Leslie	401VE0030VWC **Leslie_WB1**	Default guide signing message

SB 404 at VanHorne	401VE0060VSF **DVP_SB1**	Scheduled safety message
NB DVP at Three Valley	401VE0070VNF **DVP_NB1**	Scheduled safety message
WB 401 near Victoria Park	401VE0040VWE **VictoriaPark_WB1**	Scheduled safety message

EVALUATION COMMENT AND ACTION

A comment from MTO: Re-design this scenario to be during the peaks with various traffic flow conditions defined in different links within the network. (Some sections with consecutive very slow conditions in both express and collector as well).

In response to MTO's comment, various traffic conditions defined in different links within the network could initiate multiple congestion events within the network. This suggestion is good from an operational point of view. However, the scenario was prepared to test how the ISMS prototype responded to a predetermined traffic condition in a roadway section. A full rule set for multiple congestion events is out of the study scope and recommended for future development.

1st Evaluation

The activated signs and messages did not match.

The congestion control strategies from both systems were reviewed. COMPASS used the congestion zone concept while the ISMS used the queue length concept. The activated signs in the ISMS system cover all important diversion locations, including the sign in the queue, the upstream diversion point and the upstream connecting freeway. The messages generated by the ISMS system display the range of congestion. Because the queue length concept is currently adapted in many regions, we determined this strategy should remain in the ISMS.

EVALUATION NO.	**6**	
SCENARIO	**Collector (or Express) Total Blockage Roadwork**	
Purpose	Demonstrate capability to select CMS signs and compose messages in response to a Collector (or Express) total blockage roadwork.	
Existing Condition Prior to the Test Event	Time of day: 01:00 AM Current traffic condition: Moving well CMS display: Default messages	
Event Inputs	Event: Roadwork Location: Collector, between downstream of interchange Dufferin St. and downstream of interchange Bathurst St. (All links between node C11 and node C6) Blockage pattern: Total roadway blockage Severity: Medium-high Traffic Condition: Moving slowly on links between C11 and C14	
ISMS FINAL OUTPUTS		
CMS Location	Sign Name	Message
1st Upstream	Bathurst_WB2	1st Message : "Collector All Lanes Blocked Beyond Allen Traffic Must Exit At Allen" 2nd Message: "Express Congested To Beyond Allen"
2nd Upsream	Leslie_WB1	1st Message: "Collector All Lanes Blocked Beyond Allen Thru Traffic Use Express" 2nd Message: "Express Congested From Beyond Avenue Rd. To Beyond Allen"
3rd Upsream	VictoriaPark_WB1	"Collector All Lanes Blocked Beyond Allen Thru Traffic Use Express"
Connecting Roadway	Yonge_WB1	1st Message: "Collector All Lanes Blocked Beyond Allen Thru Traffic Use Express" 2nd Message: "Express Congested From Beyond Avenue Rd. To Beyond Allen"
	Allen_NB2	1st Message: "401 Collector All Lanes Blocked Beyond Allen" 2nd Message; "Collector Congested From Beyond Avenue Rd. To Beyond Allen"
	DVP_SB1	"401 Collector All Lanes Blocked Beyond Allen"
	DVP_NB1	"401 Collector All Lanes Blocked Beyond Allen"
COMPASS OUTPUTS		
WB coll at basketweave	401VE0010VWC **Keel_WB1**	Scheduled safety message
WB exp at basketweave	401VE0010VWE **Keel_WB2**	Scheduled safety message
NB Allen to WB	401VE0020VWR	401WEST COLLECTOR CLOSED

401 ramp	**Alan_NB2**	^BEYOND ALLEN ^TO KEELE
NB Allen to 401 ramps	401VE0010VNA **Alan_NB1**	Scheduled safety message
WB coll west of Avenue Road	401VE0020VWC **Bathurst_WB2**	^COLLECTOR LANES CLOSED ^BEYOND ALLEN ^TO KEELE
WB exp near Yonge	401VE0030VWE **Yonge_WB1**	^COLLECTOR LANES CLOSED ^BEYOND ALLEN ^TO KEELE
WB coll near Leslie	401VE0030VWC **Leslie_WB1**	^COLLECTOR LANES CLOSED ^BEYOND ALLEN ^TO KEELE
SB 404 at VanHorne	401VE0060VSF **DVP_SB1**	401WEST COLLECTOR CLOSED ^BEYOND ALLEN ^TO KEELE
NB DVP at Three Valley	401VE0070VNF **DVP_NB1**	401WEST COLLECTOR CLOSED ^BEYOND ALLEN ^TO KEELE
WB 401 near Victoria Park	401VE0040VWE **VictoriaPark_WB1**	^COLLECTOR LANES CLOSED ^BEYOND ALLEN ^TO KEELE

EVALUATION COMMENT AND ACTION

1st Evaluation

The ISMS outputs were as follows:

Bathurst_WB2	"Collector All Lanes Blocked Beyond Dufferin St Traffic Must Exit At Allen Rd."
Leslie_WB1	"Collector All Lanes Blocked Beyond Dufferin St Use Allen Rd"
Yonge_WB1	"Collector All Lanes Blocked Beyond Dufferin St"
Allen_NB2	"401 Collector All Lanes Blocked Beyond Dufferin St"

The activated signs from ISMS and COMPASS were different.

The rule in the ISMS prototype handled only 2 upstream diversion points and 1 upstream sign on all connecting roadways. The sign selection rule set in ISMS under this scenario needs to be adjusted to 3 upstream diversion points. The messages were similar.

2nd Evaluation

The activated signs from ISMS and COMPASS are the same. The messages are similar.

A congestion event was included and the congestion message was displayed as the 2nd message. The message combination could not be used in this scenario due to the restriction of the sign size. The rule uses a multiple-message strategy to show both messages on the same sign instead of message combination.

EVALUATION NO.	**7**
SCENARIO	**Severe Rain (Road Condition)**
Purpose	Demonstrate capability to select CMS signs and compose messages in response to rain.
Existing Condition Prior to the Test Event	Time of day: 11:00 Am Current traffic condition: Moving well CMS display: Default messages
Event Inputs	Event: Rain Location: Between downstream of interchange Dufferin St. and downstream of interchange Bathurst St. (All links between node C11 and node C6; all links between node E6 and E4) Blockage pattern: N/A Severity: High Traffic condition: Moving well on all links

ISMS FINAL OUTPUTS

CMS Location	Sign Name	Message
1st Upstream	Bathurst_WB2	"Severe Rain From Bathurst St. to Dufferin St. Drive With Care"
	Bathurst_WB1	"Severe Rain From Bathurst St. to Dufferin St. Drive With Care"
2nd Upsream	Leslie_WB1	"Severe Rain From Bathurst St. to Dufferin St. Drive With Care"
	Yonge_WB1	"Severe Rain From Bathurst St. to Dufferin St. Drive With Care"
Connecting Roadway	Allen_NB1	"Hwy 401 Severe Rain From Bathurst St. to Dufferin St. Drive With Care"
	Allen_NB2	"Hwy 401 Severe Rain From Bathurst St. to Dufferin St. Drive With Care"

COMPASS OUTPUTS

EVALUATION COMMENT AND ACTION

COMPASS has no response for severe rain at the moment and therefore no outputs were obtained from COMPASS.

This scenario demonstrates the ISMS prototype has the ability to handle weather type events.

EVALUATION NO.	**8**
SCENARIO	**Event Combination 1 – 1**
Purpose	Demonstrate capability to combine events
Existing Condition Prior to the Test Event	Event: Stalled vehicle on the right lane downstream of Dufferin St. in the Collector. (link from node C7 to node C6) Bathurst_WB1: "Collector 1 Right Lane Blocked Beyond Allen" Bathurst_WB2: "Collector 1 Right Lane Blocked Beyond Allen" Allen_NB1 "401 Collector 1 Right Lane Blocked Beyond Allen" Time of day: 11:00 PM Current Traffic condition: Moving well on all links
Event Inputs	Event: Traffic collision Location: Collector, at further downstream (100 meters away) of interchange Dufferin St. (link from node C7 to node C6) Blockage pattern: Middle lane Severity: Medium – Low Traffic condition: Moving well on all links

ISMS FINAL OUTPUTS

CMS Location	Sign Name	Message
1st Upstream	Bathurst_WB2	"Collector 2 Right Lanes Blocked Beyond Allen "
Connecting Roadway	Yonge_WB1	"Collector 2 Right Lanes Blocked Beyond Allen "
	Allen_NB1	"Collector 2 Right Lanes Blocked Beyond Allen "

COMPASS OUTPUTS

EVALUATION COMMENT AND ACTION

COMPASS has no existing response for combined events and therefore no outputs were obtained from COMPASS.

The ISMS prototype can combine two nearby lane-blocked events. This function can increase the flexibility of the ISMS system.

EVALUATION NO.	**9**
SCENARIO	**Event Combination 1 – 2**
Purpose	Demonstrate capability to combine events
Existing Condition Prior to the Test Event	Based on the previous condition (Combining two events in the event combination 1-1)
Event Inputs	Event: Congestion (due to previous two events) Location: between interchange Dufferin St. and interchange Bathurst St. (All links between node C11 to nod C7) Blockage pattern: N/A Severity: High Time of day: 11:00 PM Current Traffic condition: Moving very slow on links between node C11 and node C7

ISMS FINAL OUTPUTS

CMS Location	Sign Name	Message
1st Upstream	Bathurst_WB2	"Collector Right 2 Lanes Blocked Beyond Allen Congestion Beyond Bathurst St."
Connecting Roadway	Bathurst_WB1	"Collector Right 2 Lanes Blocked Beyond Allen Congestion Beyond Bathurst St."
	Allen_NB1	"Collector Right 2 Lanes Blocked Beyond Allen Congestion Beyond Bathurst St."

COMPASS OUTPUTS

EVALUATION COMMENT AND ACTION

COMPASS has no existing response for combined events and therefore no outputs were obtained from COMPASS.

The ISMS prototype can combine two nearby events: lane-blocked event and congestion event. This function can increase the flexibility of the ISMS system.

EVALUATION NO.	**10**
SCENARIO	**Display Multiple Messages**
Purpose	Demonstrate capability to handle multiple messages
Existing Condition Prior to the Test Event	Event : Traffic collision on the right lane at the downstream of Dufferin St. in the collector. (Link from node C7 to node C6) Bathurst_WB1: "Collector Right 1 Lane Blocked Beyond Dufferin St" Bathurst_WB2: "Collector Right 1 Lane Blocked Beyond Dufferin St" Allen_NB2 "401 Collector Right 1 Lane Blocked Beyond Dufferin St" Time of day: 11:00 AM Current Traffic condition: Moving well on all links
Event Inputs	Event: Rain Location: Between downstream of interchange Keele St. and interchange Allen Rd. (All links between node C10 and C3; all links between node E5 and node E3) Blockage pattern: N/A Severity: High Traffic condition: Moving well on all links

ISMS FINAL OUTPUTS

CMS Location	Sign Name	Message
Caught in Weather	Keele-WB1	"Severe Rain To Keele St. Drive With Care"
	Keele-WB2	"Severe Rain To Keele St. Drive With Care"
1st Upstream	Bathurst_WB2	Msg 1: "Collector Right 1 Lane Blocked Beyond Dufferin St. " Msg 2: "Severe Rain From Allen Rd. to Keele St. Drive with Care"
	Bathurst_WB1	Msg 1: "Collector Right 1 Lane Blocked Beyond Dufferin St. " Msg 2: "Severe Rain From Allen Rd. to Keele St. Drive with Care"
2nd Upsream	Leslie_WB1	"Severe Rain From Allen Rd. To Keele St. Drive With Care"
	Yonge_WB1	"Severe Rain From Allen Rd. To Keele St. Drive With Care"

Connecting Roadway	Allen_NB1	Msg 1: "401 Collector Right 1 Lane Blocked Beyond Dufferin St. " Msg 2: "Severe Rain From Allen Rd. to Keele St. Drive with Care"
COMPASS OUTPUTS		
EVALUATION COMMENT AND ACTION		
COMPASS has no existing response for combined events and therefore no outputs were obtained from COMPASS. The ISMS prototype can display two messages in response to two different events on the same sign. This function can increase the flexibility of the ISMS system.		

EVALUATION NO.	**11**
SCENARIO	**Multiple Stages of an Event**
Purpose	Demonstrate capability to handle multiple stages of an event
Existing Condition Prior to the Test Event	Time of day: 11:00 PM Current traffic condition: Moving well CMS display: Default messages
Event Inputs	Stage 1: Incident just occurs Event: Traffic collision Location: Collector, downstream of interchange Dufferin St. (link from node C7 to node C6) Blockage pattern: Right 2 lanes Severity: Medium – Low Stage 2: Emergency aid on scene and block all lanes on collector Event: Same event Blockage pattern: All lanes Severity: Medium - High Stage 3: Collision scene clear-up and block 1 right lane Event: Same event Blockage pattern: 1 right lane Severity: Medium – Low Stage 4: Collision site has returned to normal operation Event: Same event Blockage pattern: None Severity: None Traffic conditions: moving well on all the links in all stages

ISMS FINAL OUTPUTS

CMS Location	Sign Name	Message
Stage 1		
1st Upstream	Bathurst_WB2	"Collector Right 2 Lanes Blocked Beyond Dufferin St"
Connecting Roadway	Yonge_WB1	"Collector Right 2 Lanes Blocked Beyond Dufferin St"
	Allen_NB2	"401 Collector Right 2 Lane Blocked Beyond Dufferin St"
Stage 2		
1st Upstream	Bathurst_WB2	"Collector All Lanes Blocked Beyond Allen Traffic Must Exit At Allen"
2nd Upsream	Leslie_WB1	"Collector All Lanes Blocked Beyond Allen Thru Traffic Use Express"
3rd Upsream	VictoriaPark_WB1	"Collector All Lanes Blocked Beyond Allen Thru Traffic Use Express"
Connecting Roadway	Yonge_WB1	"Collector All Lanes Blocked Beyond Allen Thru Traffic Use Express"
	Allen_NB2	"401 Collector All Lanes Blocked Beyond Allen"

	DVP_SB1	"401 Collector All Lanes Blocked Beyond Allen"
	DVP_NB1	"401 Collector All Lanes Blocked Beyond Allen"
Stage 3		
1st Upstream	Bathurst_WB2	"Collector Right 1 Lane Blocked Beyond Dufferin St"
Connecting Roadway	Yonge_WB1	"Collector Right 1 Lane Blocked Beyond Dufferin St"
	Allen_NB2	"401 Collector Right 2 Lane Blocked Beyond Dufferin St"
Stage 4		
1st Upstream	Bathurst_WB2	Default
Connecting Roadway	Yonge_WB1	Default
	Allen_NB2	Default
COMPASS OUTPUTS		
Stage 1		
NB Allen to WB 401 ramp	401VE0020VWR **Alan_NB2**	+ 1 RGHT LANE BLOCKED (401) IN COLLECTOR WEST BEYOND ALLEN
WB coll west of Avenue Road	401VE0020VWC **Bathurst_WB2**	^1 RIGHT LANE BLOCKED ^IN COLLECTOR ^BEYOND ALLEN
WB exp near Yonge	401VE0030VWE **Yonge_WB1**	^EXRPESS MOVING WELL ^COLLECTOR MOVING SLOWLY ^BEYOND NEXT TRANSFER
Stage 2		
NB Allen to WB 401 ramp	401VE0020VWR **Alan_NB2**	+ COLLECTOR LANES (401) BLOCKED WEST BEYOND ALLEN
WB coll west of Avenue Road	401VE0020VWC **Bathurst_WB2**	^COLLECTOR LANES BLOCKED ^BEYOND ALLEN ^THRU TRAFFIC USE EXPRESS
WB exp near Yonge	401VE0030VWE **Yonge_WB1**	^COLLECTOR LANES BLOCKED ^BEYOND ALLEN ^THRU TRAFFIC USE EXPRESS
WB coll near Leslie	401VE0030VWC **Leslie_WB1**	^COLLECTOR LANES BLOCKED ^BEYOND ALLEN
SB 404 at VanHorne	401VE0060VSF **DVP_SB1**	+ COLLECTOR LANES (401) BLOCKED WEST BEYOND ALLEN
NB DVP at Three Valley	401VE0070VNF **DVP_NB1**	+ COLLECTOR LANES (401) BLOCKED WEST BEYOND ALLEN
WB 401 near Victoria Park	401VE0040VWE **VictoriaPark_WB1**	^COLLECTOR LANES BLOCKED ^BEYOND ALLEN
Stage 3		
NB Allen to WB 401 ramp	401VE0020VWR **Alan_NB2**	+ 1 RGHT LANE BLOCKED (401) IN COLLECTOR WEST BEYOND ALLEN
WB coll west of Avenue Road	401VE0020VWC **Bathurst_WB2**	^1 RIGHT LANE BLOCKED ^IN COLLECTOR ^BEYOND ALLEN

WB exp near Yonge	401VE0030VWE **Yonge_WB1**	^EXRPESS MOVING WELL ^COLLECTOR MOVING SLOWLY ^BEYOND NEXT TRANSFER
Stage 4		
1st Upstream	Bathurst_WB2	Default
Connecting Roadway	Yonge_WB1	Default
	Allen_NB2	Default

EVALUATION COMMENT AND ACTION

MTO Outputs: Refer to Scenarios 2 and 3 and then back to 2 and then free flow condition as illustrated above. The outputs are copied from Scenarios 2, 3, and then 2 for the evaluation.

The activated signs and messages were similar. This scenario proves the ISMS prototype could handle multiple stages.

EVALUATION NO.	**12**
SCENARIO	**Add A New Sign**
Purpose	Demonstrate capability to incorporate a new sign without rule changes
Existing Condition Prior to the Test Event	Time of day: 11:00 AM Current traffic condition: Moving well CMS display: Default messages
Event Inputs	Preparation: Add a sign to Allen Rd SB direction prior to exit ramps to Hwy 401 (Allen-SB1) Event: Traffic collision Location: Collector, downstream of interchange Dufferin St. (link from node C7 to node C6) Blockage pattern: Right 2 lanes Severity: Medium – Low

ISMS FINAL OUTPUTS

CMS Location	Sign Name	Message
1st Upstream	Bathurst_WB2	"Collector Right 2 Lanes Blocked Beyond Dufferin St"
Connecting Roadway	Bathurst_WB1	"Collector Right 2 Lanes Blocked Beyond Dufferin St"
	Allen_NB2	"401 Collector Right 2 Lanes Blocked Beyond Dufferin St"
	Allen_SB1	"401 Collector Right 2 Lanes Blocked Beyond Dufferin St"

COMPASS OUTPUTS

EVALUATION COMMENT AND ACTION

The ISMS prototype added the sign into the sign navigation database within 5 minutes. The system selected this sign in response to an event without changing any rules.

For COMPASS, this new sign uses the same message format as Allen NB to401 WB sign. However, the modification is beyond adding a new message template. This modification involves at least some substantial number of traffic plans (i.e., 70 or more) that need to be changed in order to include this sign.

EVALUATION NO.	**13**
SCENARIO	**Change Rules**
Purpose	Demonstrate capability to change of rules which affect all sections
Existing Condition Prior to the Test Event	Time of day: 11:00 AM Current traffic condition: Moving well CMS display: Default messages
Event Inputs	Preparation: Sign-extent rule for collector (or express) blockage incident is changed to 2nd upstream sign. Event: Traffic collision Location: Collector, downstream of interchange Dufferin St. (link from node C7 to node C6) Blockage pattern: 1 right lane Severity: Medium – High

ISMS FINAL OUTPUTS

CMS Location	Sign Name	Message
1st Upstream	Bathurst_WB2	"Collector 1 Right Lane Blocked Beyond Dufferin St"
2nd Upstream	Leslie_WB1	"Collector 1 Right Lane Blocked Beyond Dufferin St"
Connecting Roadway	Yonge_WB1	"Collector 1 Right Lane Blocked Beyond Dufferin St"
	Allen_NB2	"401 Collector 1 Right Lane Blocked Beyond Dufferin St"
	Allen_SB1	"401 Collector 1 Right Lane Blocked Beyond Dufferin St"

COMPASS OUTPUTS

EVALUATION COMMENT AND ACTION

Any rule change would result in great efforts to modify many traffic plans for COMPASS and therefore no outputs were obtained from COMPASS.

For the ISMS prototype, the modification was done in 5 minutes. The changed rule can be applied to all the roadway sections.

A 2nd evaluation was then conducted and the incident location was relocated in the link between node E4 and node E5. The rest of conditions are the same. The ISMS outputs are as follows:

Bathurst_WB1	""Express 1 Right Lane Blocked Beyond Allen"
Yonge_WB1	""Express 1 Right Lane Blocked Beyond Allen"

Bathurst_WB2	""Express 1 Right Lane Blocked Beyond Allen"
Allen_NB2"	"401 Express 1 Right Lane Blocked Beyond Allen"
Allen_SB1"	"401 Express 1 Right Lane Blocked Beyond Allen"

The results of the 2nd evaluation showed that this new rule can be applied to other roadway sections. It demonstrates the ISMS prototype is flexible and efficient in changes of rules.

4.3 Summary

The results of the evaluation were summarized as follows:

1. During the evaluation process, the traffic responses collected from MTO included traffic congestion. However, traffic responses from ISMS were initially generated based on the assumption that the traffic upstream impact was not significant at the beginning of the event. This assumption yielded the differences in responses between ISMS and COMPASS. After adding a traffic congestion event into the evaluation scenarios, the results from the ISMS matched to COMPASS (refer to Scenario 2 for an example). In addition, the sign messages generated by ISMS combined the incident and the congestion messages on a same sign, while COMPASS displays a single message on each sign. The results from Scenarios 2, 3, 4, 6, and 10 demonstrated that multiple messages could be displayed either in a combined format or in rotation in order to provide more information.

2. The sign message content from COMPASS was similar but not the same as ISMS because the ISMS adopted a general format that is not specific to the needs and sign sizes of COMPASS. The general format includes information on the problem, location and advisory, and is the format commonly used in most ATMS's. Of course, the message content is always subject to the practices of local jurisdiction's traffic engineers.

3. For Scenario 3 – Collector Total Blockage Incident, the number of activated signs and messages generated by the ISMS were different from COMPASS. This difference was because the rule set for this scenario was different from the practice used in COMPASS. After the rule was adjusted to match the COMPASS practice, the results from the ISMS matched COMPASS. It is important to note that the rule change was completed within 5 minutes, and the test repeated. This demonstrates the ease of maintenance of the ISMS.

4. For Scenario 5 – Express Congestion, the number of activated signs and message content of ISMS were different from COMPASS due to the difference in traffic response strategies. The ISMS strategy tackles the queue condition and the range, while COMPASS monitors the congestion level of the congestion zone. COMPASS activated one sign in the upstream and ISMS activated three signs to advise the drivers caught both in and upstream of the queue end in the Express and Collector lanes. The sign messages generated by the ISMS displayed the locations of queues, where COMPASS displayed the congestion level of the congestion zone. The traffic response strategy for congestion in the ISMS provides more information on queues and is currently adopted in many regions; therefore, we determined that this strategy should remain.

5. Conclusions and Recommendations

5.1 Conclusions

As a result of this project, the ISMS concept was proven to be:

1. Qualified, because a general set of rules was able to generate traffic responses that matched specific COMPASS response scenarios. Applied to other highway sections, this set of rules generated similar results.

2. Efficient, because the time required to define and modify rules took as little as a few minutes.

3. Flexible and easy for traffic engineers to update, because rules were specified in plain English (i.e., phrases used to describe events, conditions and actions) and did not require knowledge of computer programming or other software programs.

4. Cost effective, because it was developed using the XML language, which is free, easy to use, and in common use in many web information exchange applications.

5.2 Recommendations

The ISMS is a prototype system that proves that a rule-based concept using non location-specific rules can produce valid responses for freeway traffic management systems. If the concept is to be adopted in a full implementation, there are a few extensions and further work that we recommend:

1. Some functions and requirements that are necessary to facilitate the daily ATMS operational activities were not included in the prototype.

    - Automatic event assessment; and
    - Manual modification of the suggested traffic responses.

    Automatic event assessment determines the event properties and impact on the traffic conditions. Manual modification of the suggested traffic responses allows users to change the suggested traffic responses based on their practical judgment.

2. The ISMS currently manages only the initiation of the event. In order to manage the full event life cycle, it would need to be extended to manage the event update and termination phases.

3. The ISMS currently manages only one sign type. Most operational systems use several sign types; therefore, the ISMS would need additional rules to be able to determine the appropriate message content depending on the sign type.